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Final Report

Assessment of the Economic Benefits of Chlor-Alkali Chemicals to the United States and Canadian Economies

Prepared for

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Executive Summary

Every day, U.S. and Canadian consumers benefit from chlorine and chlorine-based products. When someone takes a drink of water, pours bleach into a washing machine, or buys cooking oil in a PVC container, he or she benefits from chlorine. Every time consumers use automobiles, buy produce in the supermarket, fill prescriptions in a drug store, or take pictures of their families, they are also benefitting from chlorine. Water purification, bleaches, plastics like PVC, crop protection chemicals, pharmaceuticals, and the manufacture of photographic film are only a few examples of how U.S. and Canadian consumers gain from processes and products that use chlorine.

Even though the use of chlorine chemistry results in substantial economic benefits in most sectors of our society, consumers may not realize how broadly this element touches their daily lives. Most people generally are only aware of chlorine's direct uses, but *direct consumption* is one of three distinct ways in which society uses chlorine and its coproducts. The element is also incorporated in other *consumer products*, providing them with specific, desirable characteristics, and it is used to *facilitate* the manufacture of hundreds of other products.

Chlorine has become important in these diverse applications because of its physical and chemical properties. There are some instances where other elements can replace chlorine with modest incremental cost or performance penalties, but in most instances the use of alternative processes or materials entails significant performance loss or cost increases. In some cases, the alternative processes or materials are less environmentally friendly or present health risks.

In spite of the broad range of uses and benefits from chlorine, there are certain groups that propose a total ban on chlorine production and use because some chlorine-containing compounds have been found to pose unacceptable health and environmental risks. These risks should not be taken lightly, and any situation where chlorine-dependent processes or chlorine-containing compounds create unacceptable health and environmental risks should be corrected. In April 1992 the International Joint Commission on Great Lakes Water Quality recommended that the United States and Canada consider phasing out the use of chlorine and chlorine-containing compounds as industrial feedstocks. But any public policy debate concerning the banning of all chlorine production and use should take into account not only any risks associated with chlorine's uses but also the social and economic impacts of such a ban on the United States and Canada and the risks associated with the use of substitute products.

In this study, Charles River Associates (CRA) was commissioned to conduct an independent analysis to estimate the magnitude of the *net costs* of a chlorine ban, which represent the *benefits* (or savings) that chlorine currently provides to the consumer and the *contributions* that chlorine-dependent industries provide to local, regional, and national economies. We did not base our cost estimates on life-cycle analyses concepts of determining the economic value of products. We assumed only that the environmental-, safety-, and health-related costs of chlorine-dependent products and their substitutes are reflected in their costs of production, and that all products will be made in full compliance with existing laws and regulations. We did not estimate the dislocation costs for the transition to a chlorine-free economy; however, *these costs would be very significant* over the period required for a transition to a chlorine-free economy.

We did find that chlorine-derived materials permeate our daily lives, although consumers are generally unaware of them. We also found that the value of these materials depends on how useful they are, *not* on how much chlorine is used to produce them. Chlorine use currently has enormous value to U.S. and Canadian consumers and local economies (see Exhibit 1).

HOW A BAN ON CHLORINE USE WOULD AFFECT CONSUMERS AND LOCAL ECONOMIES

For this project, CRA set out to determine not only the current (1990) economic benefits and contributions of chlorine-dependent industries, but also what the economic cost would be if the chlorine-dependent industries ceased to exist. These are our major findings.

- Using substitutes for chlorine-based products and processes would cost consumers an additional $91 billion per year in the United States and $11 billion per year in Canada.

Exhibit 1. 1990 Value of Chlorine Chemistry

To Consumers	Units	Economic Value		
		United States	Canada	Total
Economic benefits				
In direct uses	$Billion/Year[1]	9.8	1.2	11.0
In products containing chlorine	$Billion/Year	31.4	3.3	34.7
As a facilitator	$Billion/Year	49.9	6.8	56.7
Total	$Billion/Year	91.1	11.3	102.4
To Local Economies				
Economic contributors				
Value of sales	$Billion/Year	71.4	8.5	79.9
Employment, direct	Workers	366,700	28,400	395,100
Employment, indirect	Workers	948,300	55,600	1,003,900
Employment, total	Workers	1,315,000	84,000	1,399,000
Wages, direct	$Billion/Year	9.9	0.8	10.7
Wages, indirect	$Billion/Year	21.4	1.5	22.9
Wages, total	$Billion/Year	31.3	2.3	33.6
Gross domestic investment	$Billion	56.8	4.4	61.2
Balance of trade	$Billion/Year	+2.9	+0.1	+3.0

Note:
(1) All costs are in U.S. dollars.

SOURCE: Charles River Associates, 1993.

- The investment needed to build plants to make the substitutes would approach $67 billion. The transition would take 10 to 20 years, and consumers would more than likely be forced to shoulder the cost over this period by paying higher prices for the products and services being eliminated.

- In 1990, chlorine-dependent industries employed almost 400,000 workers. An additional 1.0 million workers are employed in related industries and services, so nearly 1.4 million jobs in 48 U.S. states and nine Canadian provinces depend on chlorine production. Total wages exceeded $33 billion. If chlorine production were shut down, many of these workers would lose their jobs, and society would bear the cost.
- Banning chlorine production would disrupt certain large and economically important markets, and the impact would be felt throughout the Western hemisphere and the world. Industries would have to substitute less efficient, more costly technologies that, in some cases, present their own health and environmental risks.

HOW CRA INVESTIGATED AND EVALUATED CHLORINE-DEPENDENT INDUSTRIES

In the course of this project, CRA investigated and evaluated chlorine from its initial production to its ultimate consumption. CRA constructed a "tree" for the element where the base is the production of elemental chlorine and its coproducts and the branches are the various industries, processes, and products that depend on it. We examined hundreds of commercial applications that include both large and small outlets for chlorine. There are thousands of other uses we did not examine and whose economic benefits are not included in our estimates. We did not estimate the retraining and other social costs associated with the potential loss of employment nor the costs of the disruption of basic community or social facilities and services caused by closing existing chlorine plants or building new facilities to manufacture the substitutes.

The chlorine uses that CRA did examine consume almost 90 percent of all chlorine currently produced. For each one we evaluated, we started with the following basic assumptions:

1. At some cost, alternatives exist for *all* uses of chlorine and chlorine-derived compounds.

2. Although we know that technology is constantly changing, we can only estimate the costs of the existing or definable technological alternatives for chlorine. As a result, we based our evaluation of chlorine substitutes on:

   - Products or processes currently or previously used;

   - Information provided in the patent literature and other sources concerning chlorine substitutes; and

   - Modified versions of existing processes that are highly likely to be technically workable.

3. All chlorine substitute materials and processes would comply with *current* environment-, safety-, and health-related laws and regulations.

In cases where more than one chlorine substitute exists, we used our best business and engineering judgment to determine the most likely alternative. Typically, we selected the substitute that would cost the consumer the least.

All information for this report came from publicly available sources and from contacts with experts in both the public and private sectors. CRA used its best business and engineering judgment to determine costs and engineering losses that would be caused by substitution, and to design economic models of consumer behavior.

CRA's analysis focuses on the extent of chlorine chemistry's influence on industrial activities and consumers' daily lives. It provides specific information on the economic tradeoffs that would result from a total ban of chlorine production and use in the United States and Canada. These tradeoffs are significant given chlorine's diverse use and the intricate association of chlorine chemistry with many technologies.

Executive Summary

Some of the uses of chlorine or products containing chlorine may have unacceptable environmental and health consequences, particularly those whose usage patterns are distributive. These distributive uses should be monitored carefully and appropriate regulatory action taken when the relevant scientific evidence has been evaluated. For purposes of this study, CRA did not evaluate the scientific evidence on chlorine uses that is being extensively reviewed by others.

SUMMARY

To summarize CRA's findings:

- Chlorine use is pervasive in our society, and the value of its use depends on how difficult it will be to find a suitable replacement for products produced from chlorine, not on how much chlorine is used to produce them.

- Based on a macroeconomic analysis of interindustry transactions data, we find that about 45 percent of all U.S. industries are *direct* consumers of chlorine and its coproducts, and that *all* industries are indirect consumers of chlorine or chlorine-dependent products.

- Our analyses show that chlorine-dependent products provide a very large range of economic benefits to consumers. They also show that substitution costs are extremely high in some cases and modest in others. Evaluation of the relative benefits and possible health and environmental costs of the use of chlorine-based and substitute materials must be carried out on a use- or product-specific basis to define the relationships between risks and benefits properly.

- Any policy decisions made on this issue that do not consider the consequences of a ban on chlorine production and use would be rash and would likely have a very damaging effect on the economic welfare of the United States and Canada.

1
Summary

Every day, U.S. and Canadian consumers benefit from chlorine and chlorine-based products. Water purification, bleaches, plastics like PVC, crop protection chemicals, pharmaceuticals, and the manufacture of photographic film are only a few examples of how U.S. and Canadian consumers gain from processes and products that use chlorine.

Even though the use of chlorine chemistry results in substantial economic benefits in most sectors of society, consumers generally are only aware of chlorine's direct uses. *Direct consumption* is one of three distinct ways in which society uses chlorine and its coproducts. Chlorine is also incorporated into *consumer products*, providing them with specific, desirable characteristics, and it is used to *facilitate* the manufacture of hundreds of other products.

Chlorine has become important in these diverse applications because of its physical and chemical properties. Other elements can sometimes replace chlorine with modest incremental cost or performance penalties, but in most instances the use of alternative processes or materials entails significant performance loss or cost increases.

In spite of the broad range of uses for and benefits from chlorine, a total ban on chlorine production and use has been proposed because certain chlorine-containing compounds have been found to pose unacceptable health and environmental risks. These risks should not be taken lightly, and any situation where chlorine-dependent processes or chlorine-containing compounds create unacceptable health and environmental risks should be corrected. In April 1992, the International Joint Commission on Great Lakes Water Quality recommended that the United States and Canada consider phasing out the use of chlorine and chlorine-containing compounds as industrial feedstocks. However, any public policy debate that proposes the banning of all chlorine production and use should take into account not only any risks associated with chlorine's use but also the social and economic impacts of such a ban on the United States and Canada and the risks associated with the use of substitute products.

Summary

According to one estimate, up to 60 percent of commercially practiced chemistry depends on chlorine. (1) If a ban were implemented, substitutes would have to be found for the products or processes now based on chlorine, new plants and equipment would have to be built to produce them, and provisions would have to be made to cope with job losses and other economic disruptions in the communities affected by the shutdown of the existing chlorine-dependent industries.

In this study, Charles River Associates (CRA) was commissioned to conduct an independent analysis to estimate the magnitude of the *net costs* of a chlorine ban, which represent the *benefits* (or savings) that chlorine currently provides to consumers and the *contributions* chlorine-dependent industries provide to local, regional, and national economies. Our production cost estimates for both chlorine-dependent and substitute products are based on the assumption that all manufacturing activities and use patterns will be in full compliance with all current laws and regulations.

We have *not* attempted to carry out a lifecycle cost analysis or to develop a methodology for total product costing for these goods because the necessary supporting data do not exist. A ban on chlorine production and use would induce *severe* dislocations to the U.S. and Canadian economies as industries abandoned existing production facilities and developed new products and processes to replace them. We did not estimate the dislocations' magnitude because of their transient nature, *but they would be very significant.* Instead, we focused on the state of the economies that would exist after chlorine had been fully displaced after a transition period of as long as 10 to 20 years.

References

(1) "Chlorine's Essential Role in Chemical Production," D. Becher, 3rd Global Chlor-Alkali Symposium, Monaco, 1992. This reference cites the role of chlorine in the German chemical industry, but CRA believes it is representative of practice in the United States and Canada as well.

ECONOMIC BENEFITS AND CONTRIBUTIONS OF CHLORINE USE

CRA's analysis shows that chlorine and chlorine-derived materials permeate both the manufacturing and the consumer economy. The analysis also indicates that the value of these materials depends on how useful they are, *not* on how much chlorine is used to produce them.

Current (1990) chlorine use has enormous value to U.S. and Canadian consumers through the economic *benefits* provided by chlorine-based products. CRA determined the *net* economic benefit to consumers of each of these uses by:

- Identifying the major uses of chlorine and its coproducts, caustic soda and potassium hydroxide;
- Identifying the most likely substitute products and processes that would have to be used if chlorine were banned; and
- Estimating the differences in consumer cost between the chlorine-based and substitute processes and products.

The economic *contributions* of chlorine-dependent industries fall into four areas: value of sales, investment, employment, and foreign trade balance. The economic benefits and the value-of-sales category of economic contributions can be broken down into the three major chlorine product sectors — direct consumption, chlorine-containing products, and chlorine-facilitated products. For convenience, we will discuss both benefits and value of sales in the next section and then address the three remaining contribution categories.

Our estimates of the total benefits and contributions of chlorine-dependent industries are summarized in Exhibits 1-1 and 1-2, respectively. The contribution estimates are based on a conservative definition: *a manufacturing activity is counted in the industry only if, in the absence of chlorine, it would be forced to shut down.*

Exhibit 1-1. Estimated 1990 Benefits of Chlorine Chemistry to Consumers

Economic Benefits	$Billion per Year(1)		
	United States	Canada	Total
In direct uses	9.8	1.2	11.0
In products containing chlorine	31.4	3.3	34.7
As a facilitator	49.9	6.8	56.7
Total	91.1	11.3	102.4

Note:
(1) All costs are in U.S. dollars.

SOURCE: Charles River Associates, 1993.

Exhibit 1-2. Estimated 1990 Economic Contributions of Chlorine-Dependent Industries

	Units	United States	Canada	Total
Value of sales	$Billion/Year	71.4	8.5	79.9
Processing plants	Plants	718	103	821
PVC fabrication plants	Plants	2,530	215	2,745
Total plants	Plants	3,248	318	3,566
Employment, direct	Workers	366,700	28,400	395,100
Employment, indirect	Workers	948,300	55,600	1,003,900
Employment, total	Workers	1,315,000	84,000	1,399,000
Wages, direct	$Billion/Year	9.9	0.8	10.7
Wages, indirect	$Billion/Year	21.4	1.5	22.9
Wages, total	$Billion/Year	31.3	2.3	33.6
Gross domestic investment	$Billion	56.8	4.4	61.2
Balance of trade	$Billion/Year	+2.9	+0.1	+3.0

SOURCE: Charles River Associates, 1993.

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Economic Benefits and Value of Sales of Chlorine Use (U.S. and Canada)

Direct Consumption

The largest direct uses of chlorine are for **bleaching pulp in paper manufacturing** and for **disinfecting drinking water and wastewater**. CRA estimates the value of chlorine sales for bleaching pulp to be $600 million in 1990. Chlorine-free pulp bleaching cycles based on oxygen, ozone, and hydrogen peroxide can be substituted for chlorine- or chlorine-dioxide-based cycles. However, using substitutes would be more costly and could release potentially toxic materials into the environment.

In **water treatment**, chlorine and chlorine-based products are used to purify more than 98 percent of U.S. drinking supplies and in more than 95 percent of the wastewater that is disinfected. However, this use consumes only modest amounts of chlorine — value of sales in the United States and Canada amounted to $70 million in 1990. Wastewater can be disinfected with UV radiation, and drinking water can be disinfected with ozone. However, these processes are costly, and the use of ozone could also release potentially toxic materials into the environment. In addition, the absence of residual chlorine in drinking water increases the risks of contamination and adverse health effects as the water moves through the distribution system to the consumer.

Sodium hydroxide (caustic soda) and **potassium hydroxide** are coproducts of electrolytic chlorine production. Sodium hydroxide represents the largest value of sales for the direct use of a chlor-alkali product. U.S. and Canadian consumption exceeded 13 million tons in 1990, with a market value of over $4 billion. In the event of a chlorine ban, sodium hydroxide could be produced through the current chemical caustic production based on naturally occurring soda ash, but this would involve an enormous expansion of existing facilities. Potassium hydroxide can be produced synthetically by modifying the Solvay process used elsewhere, but this could also have significant environmental impacts.

The potential effects of substitution for direct chlorine use appear in Exhibit 1-3. Exhibit 1-4 shows the value of sales for chlorine products used directly, which CRA estimates at over $4.9 billion in 1990.

Exhibit 1-3. Effects of Substitution for Direct Chlorine Use (U.S. and Canada)

Use	Chlorine Consumption (000 tons)[5]	Substitute	New Investment Required[1] ($Million)	Net Cost of Substitution[2] ($Million/Year)
Pulp bleaching	1,950	New process, ozone, peroxide	9,400	2,360
Water treatment	620	Ozone, UV	29,200	6,000
Sodium hydroxide	10,000[3]	Synthetic from soda ash	10,400	2,510
Potassium hydroxide	360[3]	Synthetic from potash	350	130
Total	2,570[4]		49,350	11,000

Notes:

(1) One-time investment in new plant and equipment to produce the substitutes.
(2) Annual additional cost to consumers to use the substitutes.
(3) Consumption of the hydroxides in a chlorine-free economy.
(4) Chlorine consumption for pulp bleaching and water treatment.
(5) Two thousand pound tons are used throughout this report. Consumption includes material used in the manufacture of exported products.

SOURCE: Charles River Associates, 1993.

Exhibit 1-4. Estimated 1990 Sales of Chlorine Products Used Directly (U.S. and Canada)

	Consumption (000 tons)	Value of Sales ($Million)
Pulp bleaching[1]	2,920	600
Water treatment	620	70
Sodium hydroxide	13,100	4,050
Potassium hydroxide	360	190
Total		4,910

Note:

(1) Includes sales of sodium chlorate.

SOURCE: Charles River Associates, 1993.

Chlorine-Containing Products

The manufacture of **polyvinyl chloride** (PVC) is the largest single consumer of chlorine. This product is used in numerous fabricated articles such as vinyl wallpaper, floor tiles, automobile components, siding, and pipe. The value of sales of PVC products amounted to more than $3.8 billion in 1990. Substitute materials for PVC depend on the specific use. Substitutes are mainly other plastics and metals, the production of which is energy-intensive and not without their own environmental impacts.

Other chlorine-containing plastics and **elastomers**, including polyvinylidine chloride, chlorinated polyolefins, and polychloroprene, have uses ranging from food packaging to automotive components and would be substituted for by other plastics and elastomers. Not only are the available substitutes more costly, but none can provide the utility, or performance in use, available in the chlorine-containing products. Total sales of these materials in 1990 were $760 million.

Flame resistance is an inherent and valuable characteristic of many chlorinated plastics and elastomers, and **chlorine- or bromine-containing compounds** are often added to other plastics as flame retardants. Halogen-free flame retardants are available, but they are more expensive and less effective, so their use entails a further loss in utility of the final product. The market value of these products amounted to $260 million in 1990.

Chlorinated solvents are used in a wide variety of industrial processes for cleaning parts in manufacture, as paint strippers and solvents for adhesives, in various manufacturing processes as highly effective solvents or extractants, and as dry-cleaning solvents. Nearly 800,000 tons were consumed in 1990, amounting to $690 million in sales. Consumption has been declining in recent years as users employ more effective processes that reduce the amounts released to the environment. In some cases, alternate solvents — which are mainly hydrocarbon based — can be substituted for chlorinated ones with limited replacement of process equipment. In most cases, however, eliminating chlorine use would require major changes in manufacturing processes and involve large capital expenditures. Furthermore, hydrocarbon-based solvents pose environmental risks, and their flammability often requires explosion-proof systems for their use.

Production of some chlorofluorinated compounds used as refrigerants (as well as solvents) is being phased out. Recycle and feedstock uses of these compounds continue to be sanctioned. These materials are important working fluids in industrial, commercial, automotive, and residential air conditioning systems, and sales totaled $840 million in 1990.

Hydrogen chloride, which is produced both as a byproduct of other chemical syntheses and by direct reaction between hydrogen and chlorine, is used in a variety of food processing and industrial applications. Its value of sales was $60 million in 1990. The substitutes for hydrochloric acid would depend on the application, but would be either sulfuric acid — largely a byproduct of smelting operations — or nitric acid, which is made by a series of energy-intensive processes based ultimately on natural gas.

Chlorine-containing compounds, mainly **sodium** and **calcium hypochlorites**, are widely used in household and commercial laundry bleaches and detergents, and as pool disinfectants and cleaning agents. The value of sales of sodium and calcium hypochlorites was $690 million in 1990. Certain other chemicals, such as perborates and peroxides, can be substituted for chlorine-containing ones, but they are more costly and generally less effective.

Most **crop protection chemicals**, including herbicides, pesticides, and fungicides, contain chlorine or chlorine is used in their manufacture, and few chlorine-free substitutes are available. These products are used extensively in U.S. and Canadian agriculture to enhance crop yields. Total sales of crop protection chemicals amounted to over $8.4 billion in 1990. CRA estimates that nearly 96 percent of all crop protection chemicals are based on chlorine chemistry, whose estimated sales amounted to nearly $8 billion in 1990. A ban on chlorine production would require farmers and others in the agricultural sector to adopt other production methods. The most immediate consequence to the consumer would be cost increases in food and other products resulting from decreased crop yields and the increased use of land, labor, water, and energy to produce the crops and livestock brought to market.

The potential effects of substitution for chlorine-containing products are summarized in Exhibit 1-5. Exhibit 1-6 summarizes the value of sales for all of these chlorine-containing uses, which totaled approximately $15.1 billion in 1990.

Exhibit 1-5. Effects of Substitution for Chlorine-Containing Products (U.S. and Canada)

Product	Chlorine Consumption (000 tons)[1]	Substitute	New Investment Required ($Million)	Net Cost of Substitution ($Million/Year)
PVC products	3,530	Various other plastics, metals	970	6,890
Chlorinated solvents	1,210	Other solvents, new processes	6,890	1,350
Hydrogen chloride	950	Other acids, new processes	1,050	460
Bleaches, disinfectants, and pool chemicals	280	Perborates with activators, peroxides	650	800
Polychloroprene products	140	Other elastomers	200	380
Crop protection chemicals	130	Revised farming techniques	1,500	24,300
Flame retardants	100	Organophosphorus compounds	260	180
Chlorinated polyolefin products	60	Various other plastics	170	120
Polyvinylidine chloride products	50	Various other plastics	470	180
Total	6,450		12,160	34,660

Note:
(1) Includes chlorine consumed in the manufacture of products that are exported.

SOURCE: Charles River Associates, 1993.

Exhibit 1-6. Estimated 1990 Sales of Chlorine-Containing Products (U.S. and Canada)

	Consumption (000 tons)	Value of Sales ($Million)
PVC products	4,200	3,840
Chlorinated solvents[1]	794	690
Hydrogen chloride[2]	980	60
Bleaches, disinfectants, and pool chemicals[3]	436	690
Polychloroprene products	87	260
Crop protection chemicals	–	7,960
Flame retardants[4]	93	260
Chlorinated polyolefin products	85	340
Polyvinylidine chloride products	56	160
Refrigerants[5]	373	840
Total		15,100

Notes:

(1) Includes all identified uses for chlorinated solvents.

(2) Includes only merchant sales. There is a significant volume of captive consumption.

(3) Includes sodium hypochlorite, calcium hypochlorite, and chlorinated isocyanurates.

(4) Includes brominated, chlorinated, and halophosphorus compounds.

(5) Includes F-11, F-12, F-22, and other similar products.

SOURCE: Charles River Associates, 1993.

Chlorine-Facilitated Products

Chlorine is used as an intermediate in the manufacture of a large number of commodities that do not actually contain chlorine in the final product. In most cases, chlorine-free alternate manufacturing processes can be identified, but manufacturing costs (and, consequently, product costs) generally would be significantly higher. This is the case for manufacturing **titanium dioxide** pigments used in paints, paper, plastics, and other goods; the **refrigerants** used in air conditioning; the **fluoropolymers** used in industrial applications and consumer goods, such as nonstick cookware; **polycarbonate** plastics used in consumer goods; and the **propylene oxide** and **isocyanates** used in the production of polyurethanes for a wide variety of industrial and consumer goods.

Titanium dioxide manufacture has been shifting over the past few decades toward chlorine-based technology and away from sulfate-based technology. Sales of chlorine-based titanium dioxide amounted to more than $1.5 billion in 1990.

Approximately 45 percent of propylene oxide capacity in the United States and Canada uses chlorohydrin technology, while the remaining 55 percent is based on peroxidation technology. Sales of chlorine-based propylene oxide amounted to $580 million in 1990.

Isocyanates are used in conjunction with propylene oxide to make polyurethanes. At present, all isocyanate production is based on chlorine chemistry, and the market value of these products amounted to approximately $1.4 billion in 1990.

Fluoropolymers are high-performance specialty polymers used in diverse applications like protective coatings (nonstick cookware), wire and cable, and industrial and mechanical products. All fluoropolymer production is now based on chlorine chemistry. The market value of these products amounted to $280 million in 1990.

Polycarbonates are high-performance polymers used in electronics, business machine, appliance, and automotive applications. At present, all polycarbonate production is based on chlorine chemistry. The value of sales of these resins amounted to over $1.2 billion in 1990.

In some cases, CRA was not able to identify technically viable chlorine-free ways of producing materials, and so substitution must occur at the end use. This is the case with a variety of products produced via **epichlorohydrin**, where the substitutes include a variety of other plastics and resins, and for products based on **silicones**. In the latter case, most identified substitutes have rather poor performance features because the properties of silicones are uniquely suited to their specific uses. Silicone products are used in automotive, building and construction, and consumer electronic applications. At present, all production is based on chlorine chemistry. The market value of these products amounted to almost $2 billion in 1990.

Chlorine chemistry is widely used in **pharmaceutical production**, although only about one-quarter of the drugs produced contain chlorine. If chlorine producti n were banned, the therapeutic benefits provided by these drugs would be lost, and alternate means would have to be found to satisfy healthcare needs. In all likelihood, consumers would increase their use of hospitals, nursing homes, clinics, physicians, and other healthcare practitioners, with the resulting added expenses. Although the pharmaceutical industry purchases only modest quantities of chlorine, CRA's research indicates that chlorine is an important ingredient in the manufacture of almost 85 percent of these products. Sales of all pharmaceutical products in 1990 amounted to an estimated $61 billion. The market value of these chlorine-dependent pharmaceutical products amounted to approximately $51.8 billion in 1990.

CRA found that sales of seven additional chlorine-dependent materials amounted to $390 million in 1990. We have not estimated sales for hundreds of other such materials for which either consumption or price data were not available. Therefore, the value-of-sales estimates presented here are conservative.

The potential effects of substitution for products and processes where chlorine is used as a facilitator are summarized in Exhibit 1-7. Exhibit 1-8 summarizes CRA's estimates of the sales value for these uses, which amounted to almost $59.9 billion in 1990.

Exhibit 1-7. Effects of Substitution for Chlorine Use as a Facilitator (U.S. and Canada)

Product	Chlorine Consumption (000 tons)(1)	Substitute	New Investment Required ($Million)	Net Cost of Substitution ($Million/Year)
Propylene oxide	930	Peroxidation process	1,060	190
Isocyanates	710	Carboxylation processes	1,130	380
Epichlorohydrin products	620	Various resins and plastics	120	480
Titanium dioxide	330	Sulfate process	1,850	480
Pharmaceuticals	160	Alternate healthcare practices	50	53,600
Refrigerants(2)	150	Direct fluorination process	250	550
Polycarbonate products	80	Carboxylation process	550	250
Fluoropolymer products	70	Direct fluorination process	110	240
Silicone products	30	Various other elastomers, fluids, and plastics	360	530
Total	3,080		5,480	56,700

Notes:

(1) Includes chlorine consumed in the manufacture of products that are exported.
(2) Chlorine-free refrigerants.

SOURCE: Charles River Associates, 1993.

Exhibit 1-8. Estimated 1990 Sales of Chlorine-Derived Products Not Containing Chlorine

	Consumption (000 tons)	Value of Sales ($Million)
Propylene oxide[1]	535	580
Isocyanates[2]	745	1,400
Epichlorohydrin products[3]	258	740
Titanium dioxide[4]	740	1,540
Pharmaceuticals[5]	–	51,800
Polycarbonate products	275	1,160
Fluoropolymer products	22	280
Silicone products[6]	170	1,990
Miscellaneous	–	400
Total		59,890

Notes:

(1) Represents only the estimated quantity and value of the chlorohydrin-based material.
(2) Includes TDI, MDI, and PMDI applications.
(3) Includes use in epoxy resins, polyamines, elastomers, and other.
(4) Represents only the estimated quantity and value of the chloride-based material.
(5) Represents 84.5 percent of pharmaceutical sales.
(6) Includes silicone fluids, elastomers, and resins.

SOURCE: Charles River Associates, 1993.

Employment

The chlorine industry directly employs nearly 400,000 workers and operates in 48 of the states in the United States and nine provinces in Canada. CRA identified over 800 processing plants that produce or depend on chlorine, and an additional 2,700 PVC fabrication facilities that would be closed or at least very severely affected by a chlorine ban. Since each manufacturing job creates secondary employment and wage effects, CRA estimates that an additional 1.0 million workers are employed indirectly in other industries. Thus, a total of about 1.4 million workers depend on the chlorine industry. Total wages paid to these 1.4 million workers amounted to more than $33.6 billion in 1990. The employment profile of chlorine-dependent industries in the United States and Canada is shown in Exhibit 1-9. Exhibits 1-10 and 1-11 depict the geographic distribution of chlorine-dependent processing plants and PVC fabrication plants, respectively.

Exhibit 1-9. Employment in and Wages Paid by Chlorine-Dependent Industries

	Number of Processing Plants	Number of PVC Fabrication Plants	Total Number of Plants	Direct Employment (Workers)	Total Attributable Employment (Workers)	Direct Wages ($Million)	Total Wages ($Million)
United States	718	2,530	3,248	366,738	1,314,971	9,939	31,349
Canada	103	215	318	28,350	84,529	766	2,283
Total	821	2,745	3,566	395,088	1,399,500	10,705	33,632

SOURCE: Charles River Associates, 1993.

Exhibit 1-10

Chlorine-Dependent Processing Plants

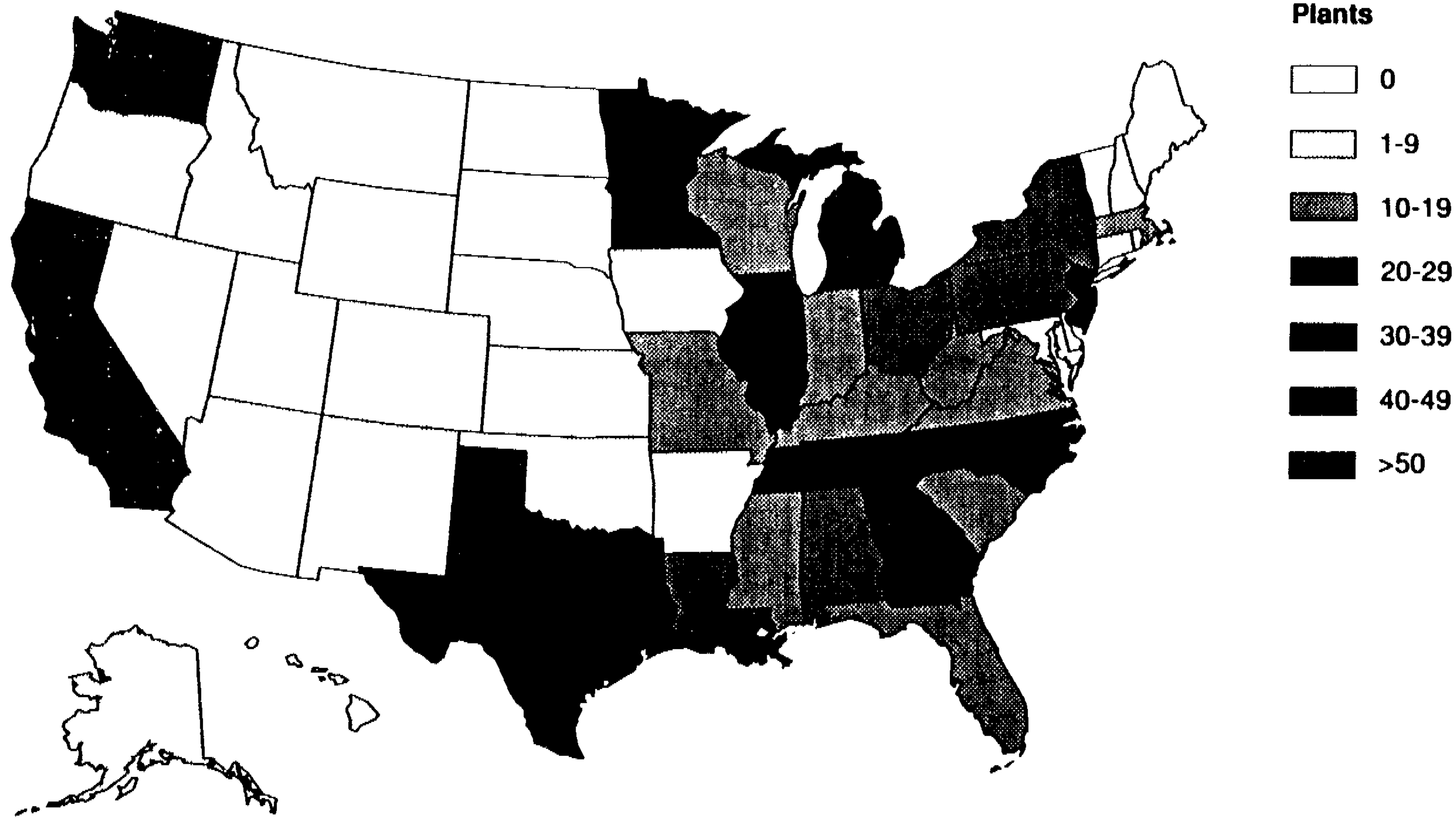
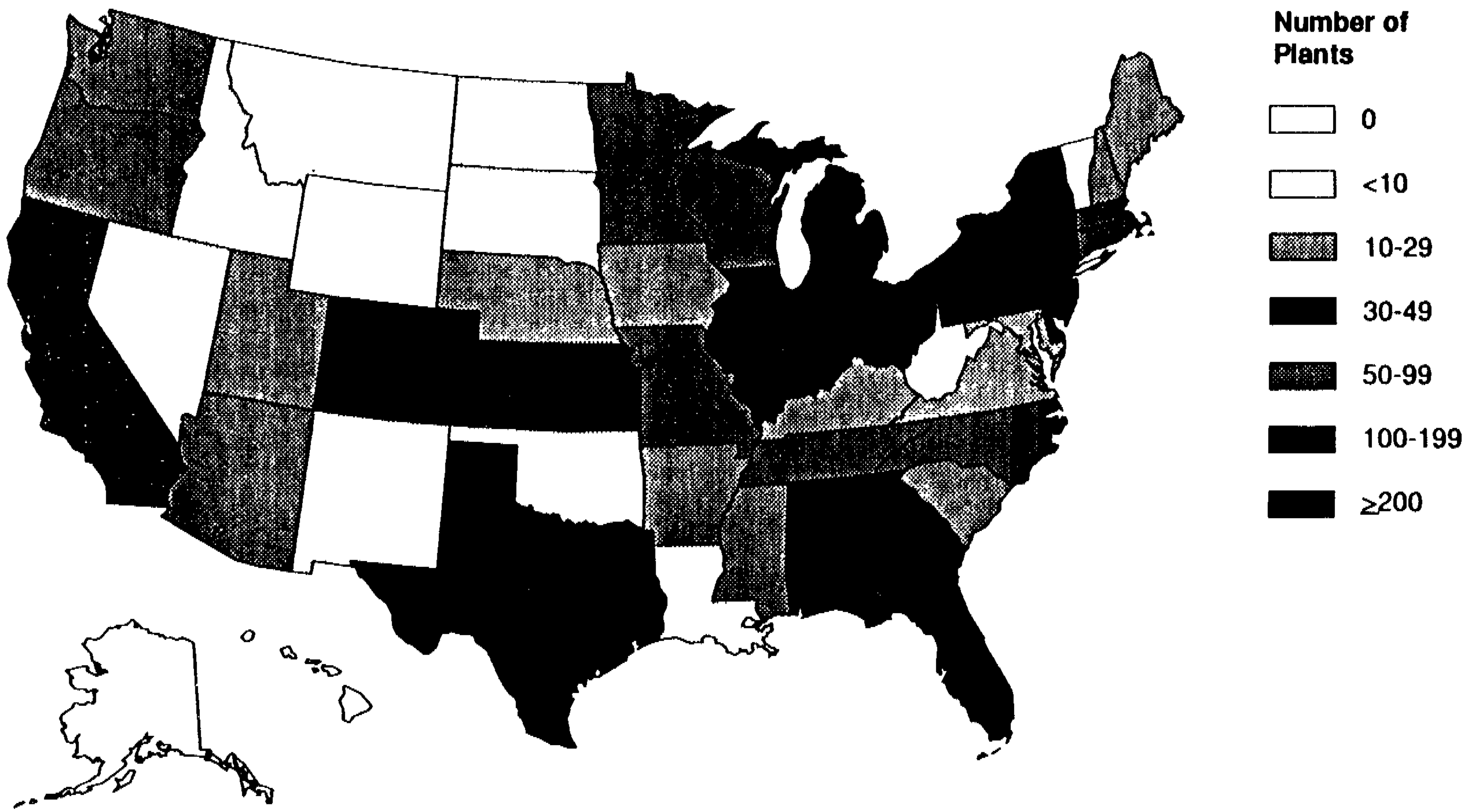


Exhibit 1-11

PVC Fabrication Plants



Summary

Investment

The gross domestic private investment of chlorine-dependent industries is estimated to be over $61 billion (see Exhibit 1-12). The geographical distribution of investment is similar to that of employment, except that primary processing plants tend to be large, capital-intensive operations, while fabrication plants tend to be small, labor-intensive operations. These plants are located in nearly every state in the United States and most provinces of Canada. In the event of a chlorine ban, most of this investment would be rendered obsolete, and the impacts would be felt nationwide.

Exhibit 1-12. Private Investment in Chlorine-Dependent Industries (U.S. and Canada)

	Number of Processing Plants	Number of PVC Fabrication Plants	Processing Investment ($Million)	PVC Fabrication Investment ($Million)	Total Investment ($Million)
United States	718	2,530	48,459	8,377	56,837
Canada	103	215	3,725	712	4,437
Total	821	2,745	52,184	9,089	61,274

SOURCE: Charles River Associates, 1993.

Foreign Trade Balance

The chlorine-dependent industries contribute more than $3.0 billion per year to the balance of merchandise trade for the United States and Canada (see Exhibit 1-13). Among the major products that contribute to the positive trade balance are titanium dioxide, sodium hydroxide, silicones, PVC, polycarbonate resins, pharmaceuticals, and crop protection chemicals. As a whole, the chemicals and allied products industry is a significant competitor in world markets and enjoys a healthy net surplus in merchandise trade. In 1990, the total U.S. chemical industry's trade surplus amounted to $16.5 billion. Thus, chlorine-dependent net trade of $2.9 billion represents about 18 percent of the industry's total. In the event of a chlorine ban, this trade surplus would disappear and, unless the rest of the world followed suit, the United States and Canada would be at a severe competitive disadvantage in world trade in these chemicals.

Exhibit 1-13. 1990 Exports and Imports of Chlorine-Dependent Products

	Value of Exports ($Million)	Value of Imports ($Million)	Value of Net Trade ($Million)
United States	5,339	2,464	2,873
Canada	362	254	108
Total	5,701	2,718	2,981

SOURCE: U.S. Department of Commerce and Statistics Canada.

MACROECONOMIC CONTRIBUTIONS

Taking a more macroeconomic approach, CRA analyzed data from the federal government's 1987 Interindustry Transactions Table (this is the most recent one), which traces flows from U.S. producing industries to U.S. consuming industries for that year. These data showed that:

- Of all the industrial sectors identified in the U.S. economy, almost 60 percent produced commodities that were required directly and indirectly for the production of chlorine and caustics.

- Tracing the consumption of chlorine and caustics "downstream" through the economy showed that these commodities were used in a variety of intermediate producing sectors of the economy and involved more than 45 percent of the industries identified in the interindustry transactions data.

- Tracing the flow of products *derived from the use of chlorine and caustics* shows that they were used, directly or indirectly, in *all* identified industries.

- The diversity of applications in which chlorine and caustics are involved in the first round of intermediate producing sectors was so great that changes in use patterns that have occurred since 1987 would not change the conclusion that *chlor-alkali-derived products touch all sectors of the economy.*

These data show dramatically the extent to which the products of chlorine chemistry are involved with the U.S. economy, and suggest that *the disruption caused by a ban on the production and use of chlorine would be enormous.*

SUMMARY

The total net cost of substitution to consumers in the United States and Canada for the products evaluated is more than $102 billion per year. Approximately $91 billion would be borne by consumers in the United States and $11 billion by consumers in Canada. Since we have not evaluated the costs of substituting for hundreds of other chlorine uses, which amount to more than 10 percent of chlorine consumption, we believe the total benefits of chlorine chemistry to U.S. and Canadian consumers are even higher.

In addition, the one-time investment cost in manufacturing capacity to produce chlorine substitutes will be approximately $67 billion. The value of sales of chlorine-dependent products total nearly $80 billion per year. Employment in chlorine-dependent industries accounted for $33.6 billion in wages in 1990. Gross domestic investment in the industry is over $61 billion, and the industry contributes more than $3.0 billion per year to the U.S. and Canadian balance of trade.

Some of the uses of chlorine or products containing chlorine may have unacceptable environmental and health consequences, particularly those whose usage patterns are distributive. These distributive uses should be monitored carefully and appropriate regulatory action taken when the relevant scientific evidence has been evaluated. For the purposes of this study, CRA did not evaluate the scientific evidence on chlorine use that is being extensively reviewed by others.

To summarize CRA's findings:

- Chlorine's use is pervasive in our society, and the value of its use depends on how difficult it would be to find a suitable replacement for products produced from chlorine, not on how much chlorine is used to produce them.

- Based on a macroeconomic analysis of interindustry transactions data, we find that about 45 percent of all U.S. industries are *direct* consumers of chlorine and its coproducts, and that *all* industries are indirect consumers of chlorine or chlorine-dependent products.

- Our analyses show that chlorine-dependent products provide a very large range of economic benefits to consumers. They also show that substitution costs are extremely high in some cases and modest in others. Evaluation of the relative benefits and possible health and environmental costs of the use of chlorine-based and substitute materials must be carried out on a use- or product-specific basis to define the relationships between risks and benefits properly.

- Any policy decisions made on this issue that do not consider the consequences of a ban on chlorine production and use would be rash and would likely have a very damaging effect on the economic welfare of the United States and Canada.

2
Introduction

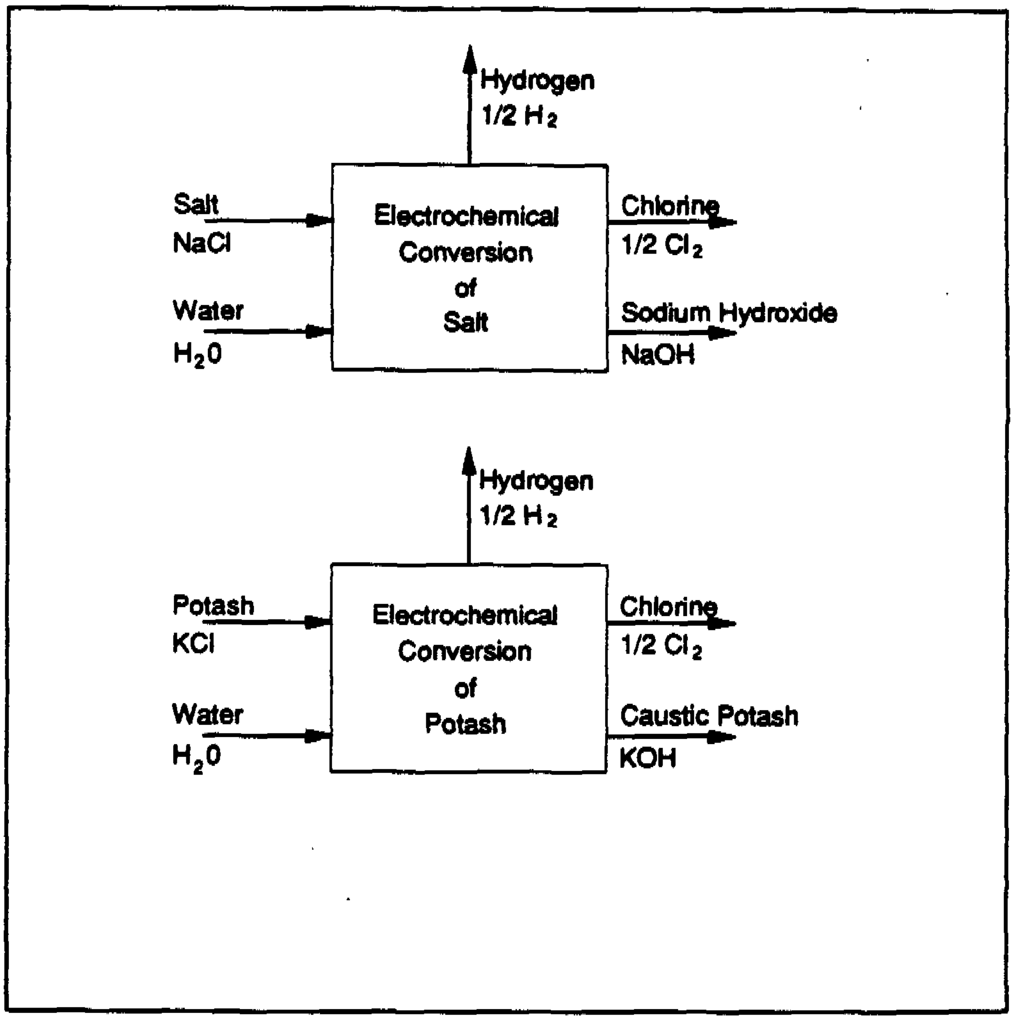
This report is concerned with the direct and indirect uses of the products of the electrochemical conversion of naturally occurring salts to chlorine and coproduced sodium and potassium hydroxides. These chemicals are considered the primary products of the chlor-alkali industry. Production of these materials is shown schematically in Exhibit 2-1. We exclude coproduction of hydrogen from these plants as well as the production of sodium carbonate (soda ash), except where it is considered as a starting material for the production of synthetic or chemical caustic soda.

Chlorine is important in many diverse applications because of its particular chemical and physical properties. It can be stored as a liquid under moderate pressure and is not corrosive when dry. It vaporizes easily and reacts rapidly and controllably with a large number of other inorganic and organic compounds to form products with desirable characteristics.

Chlorine is a strong oxidizing agent. It forms ionic chloride salts when reacted with various metallic elements and forms covalent chloride bonds when reacted with carbon and a number of other elements. The ease and specificity with which chlorine can be added to, and subsequently removed from, other elements is the basis for its widespread use. It has been estimated, for example, that up to 60 percent of commercially produced chemistry depends on chlorine. (1) In some cases, other elements can replace chlorine in a product or as a facilitator in the manufacture of other products; however, in most cases, it is very difficult to achieve the same performance in a cost-effective manner. Chemically, the easiest element in some cases to substitute for chlorine would be bromine, but bromine itself is produced commercially from bromine-rich brines using chlorine as a facilitator!

Ultimately, the chlorine that is produced mainly from purified sodium chloride (table salt) reenters the environment in a limited number of forms. A large fraction is reconverted, relatively quickly, to sodium chloride as a result of the neutralization of intermediate reaction products in industrial processes. Still more is converted to other metallic chlorides, some of which are sold as byproducts of industrial processes, or is neutralized by other bases and disposed of as soluble salts. Some is incorporated into long-lived consumer products, such as PVC pipe,

Exhibit 2-1. Electrochemical Production of Chlorine, Sodium Hydroxide, and Potassium Hydroxide



SOURCE: Charles River Associates, 1993.

which are ultimately reclaimed for reprocessing or disposed of by landfill or incineration. The balance is either incorporated into the byproducts of industrial processes that are disposed of by landfilling or incineration, incorporated into products such as pesticides and solvents that enter the environment as a consequence of their use, or released into the environment directly through such applications as pulp bleaching or water disinfection.

In 1990, the base year for this study, we estimate that U.S. and Canadian chlorine consumption was approximately 13.6 million tons, while sodium and potassium hydroxide consumption was approximately 13.1 and 0.4 million tons, respectively. The consumption of these materials in their primary end uses is summarized in Exhibits 2-2 through 2-4.

Most consumers would not recognize the role chlorine chemistry plays in their lives and the economy from such a list. More than 20 percent of chlorine's primary end uses occur in its role as a facilitator in the manufacture of other products. Furthermore, the consumer does not normally encounter most of the primary end-use products that contain chlorine, but rather the products made *from* them. For example, vinyl chloride monomer is polymerized to polyvinyl chloride, which is, in turn, compounded with plasticizers, fillers, and other materials and fabricated into the consumer products mentioned above. Thus, chlorine and its coproducts flow through an intricate web of production steps from their manufacture in chlor-alkali plants to their final use by consumers, or their uses in the manufacture of other products used by consumers.

In this report we refer, interchangeably, to the products of the chlor-alkali industry, chlorine-dependent industries, and the products of chlorine chemistry to describe the many uses of chlorine and products derived from chlorine and the coproduced hydroxides.

Examples of the sequence of transformation of the primary products of the industry into major intermediate and some consumer products are presented in the chlorine and caustic production trees presented in Appendix B.

Exhibit 2-2. Estimated 1990 Primary End-Use Patterns for Chlorine (U.S. and Canada)

Product or Use	Percent of Total Consumption
Vinyl chloride monomer	26.0
Pulp and paper	14.3
Solvents[1]	8.9
Propylene oxide	6.8
Phosgene	6.1
Epichlorohydrin	4.6
Water treatment	4.5
Hydrochloric acid[2]	2.8
Titanium dioxide	2.4
Hypochlorites	2.1
Other organic chemicals and materials	10.3
Other inorganic chemicals and materials	2.5
Miscellaneous uses	8.7
Total	100.0

Notes:

(1) Includes carbon tetrachloride, chloroform, methylene chloride, perchloroethylene, 1,1,1-trichloroethane, and trichloroethylene.

(2) Additional hydrogen chloride is produced as a byproduct of the manufacture of vinyl chloride, solvents, and other organic chemicals and materials.

SOURCE: CRA estimates, 1993, based on various industry sources.

Exhibit 2-3. Estimated 1990 End-Use Patterns for Sodium Hydroxide (U.S. and Canada)

Product or Use	Percent of Total Consumption
Pulp and paper	26.9
Propylene oxide	6.6
Cleaning products	6.3
Water treatment	5.6
Oil and gas production	3.7
Textiles and fabrics	3.2
Alumina	2.5
Other organic chemicals	17.4
Other inorganic chemicals	18.7
Miscellaneous uses	9.1
Total	100.0

SOURCE: CRA estimates, 1993, based on various industry sources.

Exhibit 2-4. Estimated 1990 End-Use Patterns for Potassium Hydroxide (U.S. and Canada)

Product or Use	Percent of Total Consumption
Potassium carbonate	22.2
Potassium phosphates	10.5
Other potassium salts	9.5
Fertilizers	6.3
Detergents	5.7
Batteries	3.8
Oil and gas products	3.0
Other chemicals	17.5
Miscellaneous uses	21.5
Total	100.0

SOURCE: CRA estimates, 1993, based on various industry sources.

Reference

(1) "Chlorine's Essential Role in Chemical Production," D. Becher, 3rd Global Chlor-Alkali Symposium, Monaco, 1992.

PURPOSE OF THIS RESEARCH

The bioaccumulation of certain chlorine-containing compounds in the Great Lakes Basin led to a recommendation by the International Joint Commission in April 1992 that the United States and Canada consider phasing out the use of chlorine and chlorine-containing compounds as industrial feedstocks. It has also been suggested that the *only* way to minimize or eliminate the health, safety, and environmental risks perceived to be associated with the use of chlorine and chlorine-containing compounds is to ban the production of elemental chlorine. The assertion that, in many cases, a shift to chlorine-free alternatives will yield substantial long-term savings and will not jeopardize the survival of the industries that use chlorine and chlorine-derived products has not been supported. Those supporting a ban on chlorine's production and use have not recommended a public policy framework within which to evaluate the economic and technological tradeoffs involved in the myriad uses of chlorine, the costs and disruptions that would occur by implementing such a ban, or the net effects on public health and the environment.

CRA believes that quantifying the benefits and contributions of chlorine chemistry is a necessary step in framing the public policy debate concerning the risks and benefits of using these products. The research described in this report was carried out to address three major issues:

- How do chlorine, chlorine-containing products, and products made using chlorine chemistry affect the consumer?
- What are the *quantitative* benefits of chlorine chemistry to the consumer, and, *qualitatively*, what are the issues associated with consumers switching to substitute products or processes?
- What are the direct and indirect economic contributions of this industry to the U.S. and Canadian economies?

Evaluating the health, safety, and environmental issues associated with the use of chlorine, its coproducts, or materials manufactured from them did not fall within the scope of this project. These issues are being investigated by others.

ASSUMPTIONS USED FOR THIS ANALYSIS

The major assumptions used in this analysis are summarized below.

The markets for chlorine-based products, their costs, and costs estimated for substitute materials are based on 1990 data and conditions. In a few cases, 1990 data were not available and data for an earlier year were used. All costs are in U.S. dollars; costs from Canadian sources have been converted to U.S. dollars at the appropriate exchange rate. In some cases, changes in industry structure are known to be occurring now, and for purposes of estimating economic benefits, we have used a "sliding scale" to establish a base or reference case for the technology. In these cases, we call attention to the changes in industry structure in our analysis.

For the benefits calculation, CRA postulates a new steady-state, long-run equilibrium for the chlorine substitutes. The effects of transient conditions are discussed qualitatively where appropriate. For this analysis, we assume that the substitute will be used at the level of economic activity prevailing in the base year, and that consumption patterns will not be altered. That is, we ignore the drag on the economy that would likely result from the replacement of chlorine-based products with more costly substitutes. *Also, we assume that policies would be enacted that would prohibit the importation of lower-cost substitutes from nations that had not banned chlorine production and use as well, and that imports of any chlorine-based products would also be banned.*

Only major uses of chlorine and chlorine-dependent products are evaluated, representing almost 90 percent of chlorine consumption. Production of a large number of products based on consumption of less than 50,000 tons per year of chlorine have not been evaluated. Therefore, the scope of the contributions and benefits estimated here is conservative because these low-consumption uses account for more than 10 percent of total consumption. We have estimated no economic benefits for products that have been banned or are subject to phase-outs, such as CFCs.

The estimate of the steady-state product costs for substitute materials is based on a "first-level" analysis of their manufacturing costs and is not exhaustive. For example, while new capital requirements for producing substitute materials are included, we have not included estimates of capital requirements for the new power plants required to support more energy-intensive industries, the new transportation networks required for distribution of larger volumes of product, and so on.

In general, chlorine-free alternatives can be provided by returning to older products or technologies that have been displaced by more efficient chlorine-based ones, or by developing new, chlorine-free technologies. Policy initiatives aimed at sunsetting chlorine production might stipulate a timeframe that could allow for the development of appropriate new technologies. Furthermore, new technologies might be introduced that change consumption patterns in the future that do not involve chlorine use. However, speculating on the evolution of technology and consumer preferences is beyond the scope of this analysis. Therefore, our evaluation of likely substitutes is based on:

- Products or processes that are in use or have been used previously;
- Information disclosed in the patent literature and other sources on the production of products or processes that do not depend on chlorine chemistry; and
- Modified versions of existing or older processes that are highly likely to be technically feasible with the substitution of chlorine-free chemistries in the manufacturing process.

Wherever possible, we have chosen chlorine-free substitutes from among products or processes that are *currently* in use. The rationale for this approach is that these products or processes are already providing consumers with options that do not involve the use of chlorine. They compete in the markets and provide consumers with benefits in use that can be compared with benefits derived from products based on chlorine chemistry. Where more than one product or process might be substituted for those currently based on chlorine chemistry, we use our best business and engineering judgment as to the substitute most likely to be used. In most cases, this is based on our estimate of the lowest likely delivered cost to the consumer.

All "new" processes and products are assumed to be in compliance with all *current* environmental, safety, and health laws and regulations. The expense of meeting these requirements is borne in the production costs.

All information for this report came from publicly available sources and from contacts with experts in both the public and private sector, and references to these sources are cited where appropriate. Our estimates of costs, our estimates of losses caused by substitution, and our design of economic models of consumer behavior are also based on our best business and engineering judgment.

ORGANIZATION OF THIS REPORT

In Chapters 3 and 4 of this report, we present our estimates of the economic benefits of chlorine chemistry and the economic contribution of the chlor-alkali and chlorine-dependent industries, respectively. In each chapter, the general methodology used to develop the estimates is described first, followed by a more detailed description of each element of the analysis. The final chapter contains a description of the macroeconomic evaluation of the impacts of the chlor-alkali industry on the U.S. economy.

Background information and appropriate supporting detail are contained in the appendices to this report.

3
Estimating the Economic Benefits of Chlorine

DEFINITION OF ECONOMIC BENEFITS

The fundamental assumption of this analysis is that the consumer derives benefits from chlor-alkali-based products because, in the absence of chlorine, consumer needs would have to be satisfied with more expensive or less useful alternative materials. The dollar value of these benefits is estimated by calculating the difference in costs between the substitute materials and the chlorine-derived materials currently in use.

Making this calculation requires that we determine both the most likely substitute material or process that would be used in the absence of the chlorine-derived material or process, and estimate the costs to produce the substitute. In calculating the benefits we attempt to determine the long-term or equilibrium costs of producing the substitute; that is, we estimate the costs associated with production of the substitute material *after* the chlorine-derived material has been displaced and the costs of dislocation have been absorbed. While we have not attempted to estimate the dislocation costs quantitatively, they are likely to be very large.

This methodology is based on an evaluation of the *current* costs of production and use of chlorine-based materials and their substitutes. It does not account, for example, for disposal costs for a product at the end of its useful life. The rationale for excluding these costs is twofold: they are not necessarily borne directly by the consumer, and they are extremely difficult to estimate in the absence of site-specific information that is not available to us. Neither does this methodology account for the possible costs of long-term environmental damage or healthcare costs that might result from the *use* of chlorine-based products *or their substitutes*. The methodology necessary to develop these types of costs, sometimes called "total product costing" or "full-cost accounting," is still being developed and could not be used to produce *quantitative* estimates for this study. (1) Where appropriate, we have addressed these issues qualitatively in the discussions of each product or use.

CALCULATION OF BENEFITS

Three types of benefit calculations have been undertaken to facilitate this analysis. The elements of each type of calculation are described briefly below. Process- and product-specific elements of each calculation are described in the sections of the chapter dealing with individual products.

Direct Substitution of Materials

Certain chlorine-based materials can be replaced directly by products that are not chlorine-based. For example, small-diameter PVC pipe can be replaced by copper tubing for use in domestic plumbing systems. In this case, the benefit to the consumer of using the PVC pipe is estimated by calculating the installed cost difference between copper tubing and PVC tubing. Here, total costs include not only the purchased cost of the materials but the installation costs as well. For other products, PVC may be replaced by different *amounts* of other plastics: the weight differences occur because of differences in both density and mechanical properties. In these cases, the consumer benefit is calculated simply as the difference between the amount of PVC product at its price and the amount of the substitute at its price.

Where appropriate, costs attributable to differing service lives are also estimated. If the substitute's life were estimated to be less than that of the chlorine-based product, CRA's estimates accounted for the equivalent amount of substitute material that would have to be purchased over the life of the PVC product. If the substitute's life were estimated to be longer than the chlorine-based product, the amount of substitute product required was decreased in proportion to the relative lives, except that no corrections were made where lives were expected to exceed 20 years because the present value of the cost differences would be small.

If the current productive capacity for the substitute would be sufficient to support the increased future demand, the purchased cost of the substitute was taken to be current (1990) cost. However, if additional productive capacity would be required, estimates were made of the capital requirements necessary to support the increase.

Capital requirement estimates for the production of existing substitute materials were obtained from the literature or by predesign estimating techniques based on production volumes. These capital estimates are not site specific and carry uncertainties of ±30 to ±50 percent. Estimates of production costs were made using the same sources, and carry uncertainties of the order of ±20 percent. Uncertainties of this magnitude are typical for these types of predesign estimates. (2)

If new capacity would be required, we examined the issue of capital recovery on the new investment. If the industry sector providing the substitute product were operating at very high capacity utilization in the base year, it would be possible to realize value-added margins in excess of the cash costs of conversion plus distribution and other expenses. In this case, a new producer might enter the market with sufficient capacity to meet the new demand without creating enough excess capacity to put downward pressure on prices. Then, the operating margins would include sufficient margins to provide an acceptable return on investment without affecting prices.

Unfortunately, there were few industries in the United States and Canada in this situation in 1990. New investments would *not* be made at their prevailing prices: prices would have to increase to an extent sufficient to permit reasonable returns on capital. In these situations, we have added a capital recovery charge of 20 percent of the new investment to the cost of the substitute material, which is equivalent to using a levelized cost factor based on 15-percent nominal interest with a ten-year recovery period.

Next, the total benefits to the consumer are calculated by multiplying the difference between the projected consumption and the projected price of the substitute material, including the capital recovery charges, and the current consumption and current price of the chlorine-based material.

Process Substitution

In many cases, the products of the chlor-alkali industry are used in the manufacture of other goods, and using a substitute would require new manufacturing processes. For example, titanium dioxide (a whitening pigment used in paints, paper, and plastics) is commercially available both from a newer chlorine-based process and an older process based on sulfuric acid. The chlorine-based route is favored in the United States because of the high environmental costs associated with operating sulfuric-acid-based plants. In this case, the benefit to the consumer of chlorine chemistry is calculated as the difference in costs between the sulfuric acid and chlorine-based routes per pound of titanium dioxide produced multiplied by the total volume of titanium dioxide consumed. Since the existing manufacturing facilities based on the chlorine route cannot be used to produce material made by the sulfuric acid route, the new investment required for the substitute process must be estimated and the costs of production must include capital recovery charges for this investment. Cost estimates for these cases were developed using the techniques described above, and are subject to the same uncertainties.

Imperfect Product and Process Substitutes

In many cases, it is not possible to identify perfect substitutes for the current chlorine-based materials or processes. For example, substituting a chlorine-free pharmaceutical for a chlorine-containing one could involve different therapeutic effects or entail contraindications that would restrict its use for some patients. In these cases, it is extremely difficult to quantify the differences in performance between chlorine-based and substitute materials and therefore to calculate the value of the chlorine-derived product benefits. The methodology we have used under these circumstances is described in detail in the benefits estimation sections below.

Other Costs

The cost differences calculated by the methodology described above do not capture the dislocation costs that would be incurred during the transition to a chlorine-free economy. During the transition, the price of chlorine-derived material would be expected to increase, since the sunsetting of chlorine production (we presume) would effectively bar new producers from entering markets currently served by these products and thus remove a constraint on prices. The price increase for chlorine-derived products would constitute an additional consumer burden. Presumably, some fraction of the increased revenues derived by the producers of chlorine-derived materials could be used to support research and development activities and construction of new facilities necessary to provide the substitute materials.

Also, the costs calculated by CRA's methodology capture only the immediate or *first-level* costs associated with the production of the chlorine-based materials and their substitutes. They do not represent estimates of life-cycle costs associated with producing the raw materials and energy necessary to produce the substitutes, the environmental costs associated with disposal of production wastes beyond those currently required by existing regulation, nor the cost of disposal of post-consumer wastes.

Furthermore, we do not estimate the economy-wide inflationary impact of these cost increases as they ripple through to final consumer demand. It is likely that, unless there were substantial gains in productivity, a chlorine ban would be highly inflationary and lead to a reduction in overall economic activity.

Neither have we considered indirect or societal costs that might be associated with the use of chlorine *or use of the substitute.* Including these types of costs and benefits, through the use of full-cost accounting, would certainly be warranted in the context of a more comprehensive evaluation of the effects of banning chlorine-based products.

Gross Versus Net Benefits

Economic impact assessments are sometimes criticized because they estimate the gross impacts, not the net impacts, of proposed regulatory actions. That is, if a material or process is banned, restricted, or heavily regulated, the associated economic impacts may result in job losses in the affected industries. However, substitute materials or processes may be developed or used, and these activities create new jobs that may not be taken into account.

It is important to note, though, that CRA's benefits-estimating methodology results in an estimate of the *net* consumer benefits. The employment associated with the production of the substitute materials, with the construction of the plants necessary to produce them, and with the R&D activities necessary to develop them is counted in the cost of the substitute material. Notwithstanding the creation of these new jobs, the extent of the increased costs of producing the substitutes, which are the benefits (or savings) of chlorine chemistry as currently practiced, would represent a tax to the economy.

References

(1) "Full-Cost Accounting," *Chemical and Engineering News*, January 11, 1993, p. 8.

(2) *Plant Design and Economics for Chemical Engineers*, M. Peters and K. Timmerhaus, 4th ed., McGraw-Hill, 1991.

ESTIMATION OF BENEFITS BY TYPES OF USE

In the sections that follow, we summarize the considerations leading to our estimates of the benefits of chlorine chemistry. We have aggregated the many uses of chlorine into three classes — direct uses, chlorine contained in products, and chlorine used as a facilitator — and describe the benefits of each use in decreasing order of chlorine consumption. The economic benefits described in the following sections are those estimated to accrue to consumers in the United States and Canada. Benefits to consumers in each country are estimated in the final section of the chapter.

Direct Uses

Pulp and Paper

Chlorine is used directly to bleach wood pulps used to produce high-quality papers. Not all pulps are bleached, but in 1990 approximately 156 mills in the United States and Canada produced about 45 million tons of bleached pulps. A variety of pulping techniques and pulp treatment sequences may be used, depending on the type of wood being pulped and the requirements of the paper products to be made from the pulp. Operations within a pulp (and paper) mill are highly integrated, with extensive recycling and recovery of intermediate wash and extraction liquors, energy integration, and byproduct recovery operations. Once the design of a mill has been set, it is not easy to make major changes in the bleaching sequence because of its integration with the rest of the plant. Pulp mills are also large consumers of caustic soda, which is added to pulping chemicals and is used to neutralize washes in the bleaching cycle and effluents. In the past, bleaching cycles were often designed to consume chlorine and caustic soda in about the same weight ratio as they are produced in electrolytic chlor-alkali plants.

The chlorine bleaches and brightens the pulp by oxidizing and solubilizing residual lignins and resin-derived materials in the digested pulp. Relatively large amounts of dissolved, chlorine-containing organic materials are contained in bleach plant effluents from mills with older bleach cycle designs, and they are not removed completely in the plant secondary treatment systems. These compounds are not completely characterized and are referred to generally as "TOCl" or "AOX." (1) Their continued released into waterways has raised environmental concerns, and regulatory reviews are underway that will likely limit their discharge.

The pulp and paper industry has been seeking to develop cost-effective technologies that would decrease the discharges of chlorinated compounds for some time. For the most part, these technologies have been based on the substitution of on-site produced chlorine dioxide for a portion of the elemental chlorine formerly used in the bleaching cycles: 30- to 70-percent substitution of chlorine dioxide for chlorine can be achieved with oxygen used to delignify the pulp and reduce the bleaching plant's load. Many such plants are now in operation. Research activities have also been directed toward radically different bleaching techniques, such as the use of enzymes, but none of these have been demonstrated commercially.

Production of market pulps with brightnesses in the range of 84–88 ISO is possible using so called ECF (elemental chlorine free) cycles, but major changes are required in both the cooking and bleaching operations. With chlorine dioxide only used in the bleaching cycle, significant amounts of oxygen and ozone would have to be used in the digestion and extraction steps. A few plants are now in operation using variations of this cycle, and they have greatly reduced discharge rates of chlorinated compounds. (2)

This type of plant would not be possible in the event of a chlorine production ban, however; rather the plant would have to be based on a TCF (totally chlorine free) cycle. It appears that such a cycle would be technically feasible if oxygen and ozone were used in the cooking and delignification operations and an oxygen-peroxide bleaching cycle were substituted for the chlorine dioxide used in the ECF cycles. It is not yet clear that the high brightness required for market pulps can be produced from all types of woods in such a cycle. It is possible that an ECF cycle plant could be retrofitted to accommodate a TCF cycle, although the costs for the latter would exceed those of any other likely cycle. (3) Plants based on more conventional cycles, and particularly those without extended oxygen/ozone delignification and brightening would have to be largely rebuilt, since retrofitting would not be economical.

In 1990, only about 2 percent of the plants producing bleached pulp were using ECF cycles, and many of the rest were using cycles with no or limited substitution of chlorine dioxide for chlorine. Thus, essentially all plants would have to be rebuilt to accommodate a TCF cycle, and the capital requirements of such a wholesale replacement in the United States and Canada would be of the order of $15 to $20 billion. (4) However, the pulp and paper industry has been under market and environmental pressure to move to more advanced — though not necessarily ECF — cycles as older plants are refurbished and new plants are built. Some of the advanced cycles are less costly than the older, "conventional" ones and will be adopted simply because they represent the best economic choice. (3) On the basis that the industry is moving in the direction of employing these advanced cycles for these conventional reasons, we have assumed that a ban n chlorine production, which would also prohibit chlorine dioxide production, would require the *retrofitting* of only half of the mills and *rebuilding* the remaining half to operate with TCF cycles. Capital requirements and operating cost estimates for conventional, advanced, and TCF plants have been taken from a recent study of plant costs. (3) The estimated costs of conversion are summarized below in Exhibit 3-1.

Exhibit 3-1. Benefits of Chlorine Chemistry in Pulp Bleaching (U.S. and Canada)

Estimated 1990 bleached pulp production (Million tons)	45.2
Estimated 1990 chlorine consumption (000 tons)	1,950
Substitute manufacturing process	Oxygen delignification, high and medium consistency ozone brightening, oxidative extraction, peroxide bleaching.
Estimated investment required ($Million)	9,400
Estimated incremental manufacturing costs ($Million/Year)	480
Estimated total costs of substitution ($Million/Year)	2,360

SOURCE: Charles River Associates, 1993.

We estimate that the net benefits to consumers of chlorine use in pulp and paper production is almost $2.4 billion per year. That is, in the absence of chlorine, pulp manufacturers would incur costs that are almost $2.4 billion per year higher than would be incurred if chlorine were used. These costs would be passed on to consumers in the form of higher prices. We estimate that one-time investments of $9.4 billion would be required to convert existing plants and build new plants capable of using chlorine-free bleaching processes. These investments would not have to be made if chlorine could be used.

water reaching the consumer generally rages between 0.1 and 3 mg/l, with a median value of about 1.1 mg/l. (1)

Effluents from sewage treatment plants may also be disinfected to prevent contamination of the body of water receiving the discharges. More than 95 percent by volume of disinfected wastewaters are treated with chlorine or chlorine-containing compounds, about 2.5 percent are disinfected by contact with ultraviolet radiation (UV), and the balance are disinfected with ozone or other chemicals. (2) The use of UV systems to disinfect wastewater tends to be favored in small plants (less than one million gallons per day capacity) where ease of control and simplicity of operation may be more important than in larger facilities. The amount of chlorine added to wastewater is highly variable and depends on the efficiency of the upstream treatment processes, the suspended solids content of the water, the nature and flow of the receiving body of water (which may vary seasonally) and the size of the treatment plant. We estimate that about 75 percent of the chlorine used in water treatment is used to disinfect wastewater, with the balance used to disinfect potable water.

With sufficient dosage and contact time, chlorine oxidizes and kills pathogens, reducing the concentration of live bacteria and viruses to levels that do not represent a public health hazard. The residual chlorine content of the treated water provides additional disinfecting capacity to destroy microorganisms that might either enter a potable water distribution system or repopulate the water through regrowth after the initial treatment step. Microbial contamination of drinking water supplies is a real public health threat; recent EPA compliance surveys show that most violations of the Safe Water Drinking Act are caused by high levels of microbes, and most of the violations were found in smaller treatment systems that have limited abilities to operate complex treatment systems. (3)

Some consumers have objected to chlorine use as a potable water disinfectant on aesthetic grounds, since high levels of residual chlorine may impart disagreeable taste and odor. Also, if chlorine is applied to water that contains significant amounts of organic compounds, including naturally occurring organic materials, it is possible to form a number of chlorine-containing compounds. These

It is likely that as plants are designed to accommodate newer bleaching cycles, efforts will be made to increase the amount of recycle within the process. This will be done to decrease the total amounts discharged from the plants to reduce treatment costs and comply with anticipated changes in permitted AOX discharges. Banning chlorine would eliminate AOX discharges, but would not eliminate the discharge of soluble, toxic compounds. The $O_2/O_3/H_2O_2$ used in TCF bleaching cycles will convert some organic constituents of the pulp into a variety of aldehydes, ketones, alcohols, acids, and other compounds whose environmental effects are not yet known. Studies of the environmental consequences of the discharge of these types of oxygenated effluents are now underway.

References

(1) "Shifting Environmental Requirements Renew Interest in Ozone Bleaching," L. Shackford, *Pulp and Paper*, October 1990, p. 55.

(2) "Development of an Ozone Bleaching Process," W. Nutt et al., *TAPPI Proceedings*, 1992 Pulping Conference, Boston,. MA, November 1992, p. 1109.

(3) "A Comprehensive Impact Analysis of Future Environmentally Driven Pulping and Bleaching Technologies," L. Brunner and T. Pulliaus, *TAPPI Proceedings*, 1992 Pulping Conference, Boston, MA, November 1992, p. 277.

(4) "TCF Conversion: Little Benefit, Huge Cost," L. Lancaster et al., *PIMA Magazine*, November 1992, p. 38.

Water Treatment

Chlorine is used directly in water treatment as a chemical disinfectant to destroy pathogens that present immediate threats to human health. Currently about 87 percent of water utilities in the United States that add a chemical disinfectant to potable water use chlorine alone, about 12 percent use chlorine and other oxidants, mainly chloramines and hypochlorites, and about one percent use other disinfectants, including ozone. (1) The amount of chlorine added to a water supply depends on local water quality and composition before treatment and the practices of the treatment plant, but it is generally added at dosage levels between about 0.2 and 10 mg/l (or ppm). The residual chlorine content of the treated compounds, referred to as disinfection byproducts, are sometimes called "tri halo methanes" or THMs, although this does not represent their chemical structure.

THM concentrations are reduced in a variety of ways, including pretreating water to remove organic precursors, reducing the chlorine dosage, using ammonia in conjunction with chlorine to form chloramines, using postdisinfection treatment, or switching to chlorine-free disinfection. Modifying chlorine-based disinfection plants to reduce THMs can create operating problems under some circumstances (1), and disinfecting with ozone produces a range of oxygenated disinfection byproducts such as aldehydes, ketones, acids, bromates, etc., that pose their own risks.

The most likely chlorine-free substitute for potable water disinfection is ozone, which is now used to disinfect about one percent of the water supplies. The process is used in more than 40 treatment plants in the United States and 50 treatment plants in Canada. Both air and gaseous oxygen are used to generate the ozone, and experience has been gained in designing and operating the complex generators and treatment systems. Ozone dosage rates between about 0.5 and 17 mg/l have been reported, but the median rate is probably about 1 to 2 mg/l. (4) In some plants, ozone disinfection is followed by addition of small amounts of chlorine or chloramines to provide residual disinfection because ozone decomposes too rapidly to provide *any* residual disinfection. This practice would not be possible if chlorine were banned, and water disinfected with only ozone would have to be protected carefully after treatment to prevent recontamination.

Widespread use of UV disinfection for potable water is unlikely because it is not effective against all microorganisms and does not provide any residual disinfection. (5) Both UV and ozone are used currently to disinfect wastewater. However, there are more UV systems than ozone systems in operation in all plant size ranges, so we have assumed that disinfection by UV would be the most likely general substitute for wastewater disinfection by chlorine.

Information is available on the size distribution of U.S. potable water treatment plants, the populations served by them, and the types of treatment and disinfection equipment used in them. (6) Data are available for the number of potable water treatment plants in some Canadian provinces (7) and on the number of wastewater treatment plants in the United States. (2) Where no data were available, we have estimated the number and size distributions of systems on a per capita basis. The costs of installing the components of UV and ozone disinfection systems have also been published (8,9) and were used to estimate capital requirements and operating costs for these systems. In addition to estimating ozone generating and contacting systems costs for potable water plants, we estimated the costs of physical pretreatment systems for plants that do not currently have them, since they are normally used to reduce the costs and increase the effectiveness of ozone treatment. We assume that all remaining surface water treatment plants that do not yet have pretreatment systems and half of the groundwater treatment plants that do not have them would install pretreatment equipment. We also add the costs of physical post-treatment to all plants not practicing it now on the basis that it is the most likely substitute for the protective benefits of residual chlorine. The estimated costs of conversion to these disinfection processes are summarized in Exhibit 3-2.

Exhibit 3-2. Benefits of Chlorine Chemistry in Water Disinfection (U.S. and Canada)

	Potable Water	Wastewater
Treatment systems affected	62,900	10,100
Estimated 1990 chlorine consumption (000 tons)	154	463
Substitute treatment process	Pretreatment by sedimentation/flocculation/ filtration, ozonation, post-treatment by flocculation/ filtration	Disinfection by UV
Estimated investment required ($Million)	22,200	7,000
Estimated incremental treatment costs ($Million/Year)	1,280	1,800
Estimated total costs of substitution ($Million/Year)	3,500	2,500

SOURCE: Charles River Associates, 1993.

A capital recovery factor of 10 percent has been used in these calculations, which is a levelized cost factor based on 9 percent interest with a 25-year recovery period. The basis for this assumption is that most treatment plants are owned by municipalities or government agencies that can acquire capital at lower cost than private enterprise. We estimate that about 40 percent of the total capital requirements for potable water treatment would be used to retrofit smaller plants treating groundwater. The average cost is estimated to be approximately $110,000 per plant for these facilities. The incremental treatment costs include the cost of power required to generate the ozone, which is more costly than the chlorine used in conventional treatment plants.

We estimate that about 50 percent of the capital requirements and incremental disinfection costs for wastewater treatment would be borne by midsize to large plants treating 10 to 100 million gallons per day. The reason for this is that few economies of scale are possible in the construction of UV disinfection facilities. Since the maximum power input to a lamp is limited, a plant treating 100 million gallons per day would require twice as many lamps as a 50 million gallon per day plant. Regular replacement of 2,000 lamps in such a plant increases maintenance costs significantly. It is possible that some larger wastewater treatment plants would find the use of ozone disinfection less costly, particularly if their suspended solids loads were significantly lower than average.

In addition to the risks involved with water supply recontamination in the absence of residual chlorine, it must be recognized that the products of ozone disinfection are often not benign. They would not be halogenated — unless halogenated precursors were present in the raw waters — but they would include a range of oxygenated compounds that are toxic themselves. In addition, it is quite possible that operating problems in the relatively simple, very small treatment plants using chlorine for disinfection would be exacerbated in plants using more complex ozone treatment. This could lead both to public health problems and environmental problems caused by the discharge of excessive amounts of ozone. (4)

References

(1) "Survey of Water Utility Disinfection Practices," Water Quality Division Disinfection Committee, *AWWA Journal*, September 1992, p. 121.

(2) "Survey on Wastewater Disinfection Practices," Water Environment Federation, 1991.

(3) *FY 1991 Compliance Report*, National Public Water Systems Supervision Program, Office of Groundwater and Drinking Waters, U.S. Environmental Protection Agency, March 1992.

(4) "Survey of Ozone Installations in North America," C. Tate, *AWWA Journal*, May 1991, p. 40.

(5) "Treatment of Microbial Contaminants in Potable Water Supplies: Technologies and Costs," J. Troyan and S. Hausen, Noyes Data Corporation, 1989.

(6) *Water Industry Data Base: Utility Profiles*, American Water Works Association, Denver, CO, 1992.
(7) "Canada's Cooperative Approach to Drinking Water Regulations," K. Decker and B. Long, *AWWA Journal*, April 1992, p. 120.
(8) "Estimating Costs for Treatment Plant Construction," S. Qasius et al., *AWWA Journal*, August 1992, p. 56.
(9) *Estimating Water Treatment Costs*, Vol. 1–4, R. Gumerman et al., EPA–600/2–79–162, U.S. Environmental Protection Agency, August 1979.

Sodium Hydroxide (Caustic Soda)

Including sodium hydroxide in the direct use category is somewhat arbitrary since only about one-third of caustic soda is used directly for pulp and paper and for water treatment. In a few products, the sodium ion derived from caustic soda plays a role analogous to chlorine when it is incorporated into products to impart specific properties in use. In some uses, it plays a role analogous to chlorine as a facilitator and does not appear in the final product. In most cases, however, caustic soda functions as a neutralizing agent for acid, and the neutralized product is then disposed. The largest identified source of consumption for caustic soda (outside of pulp and paper) is the manufacture of a large number of inorganic and organic chemicals. A significant fraction of the caustic soda consumed in these sectors is used to neutralize hydrochloric acid or to extract a chloride ion that had been incorporated in an intermediate product. For these uses, sodium hydroxide "closes the cycle," regenerating the sodium chloride starting material, which is then either recycled or disposed.

Caustic soda is sold in a variety of grades and forms. High-purity caustic, which contains low levels of chlorides and chlorates, is produced mainly in chlor-alkali plants that use mercury-cell technology. Lower-purity grades are produced in plants using diaphragm-cell technology. Newer chlor-alkali plants are based on membrane-cell technology that also produces a higher-grade product. Most material is sold either as solutions containing 50-percent sodium hydroxide or as solid flake or pellets. (1)

In its role as a general neutralizing agent, caustic soda competes with other bases such as lime and soda ash. Deciding which base to use depends on the chemistry involved, the purchased cost of the raw material, the cost of equipment to handle it, and the ease and convenience of handling the raw materials and disposing of the neutralized products.

In periods when the markets for chlorine and caustic soda are not in balance, the price of one or the other may change dramatically. When chlorine demand is slack, caustic soda supplies become tight and its price can rise dramatically. When this occurs, consumers may evaluate the costs of equipment necessary to handle the less expensive but harder to handle lime or solid soda ash. Once a decision has been made to install a lime or soda-ash-based system, caustic soda prices would have to drop to low levels to regain the lost market. Past increases in caustic prices have resulted in such substitutions in a few applications, but the capital requirements and technical problems associated with substitution of the bases greatly limit their ability to displace electrolytic caustic.

If elemental chlorine production were banned, coproduction of electrolytic caustic soda would cease and demand for caustic soda substitutes would rise. The most likely replacement would be "synthetic caustic," which is produced by treating dissolved soda ash with hydrated lime. This technology is well known, and small quantities of chemical caustic are currently being produced for consumption in the western United States at the large soda ash processing operations in Wyoming's Green River area. (2) The current market for this chemical caustic is small because of its relatively unfavorable economics *vis-à-vis* electrolytic caustic, the high costs of transporting the material to Gulf Coast and Eastern markets, and the high silica and metals contents of some grades.

If chlorine production were banned, however, total caustic demand would drop because many current uses that are tied directly or indirectly to neutralizing chloride ions would be eliminated. This would be partially offset by an increase in caustic demand for TCF pulp bleaching cycles, but we estimate that the net result would be a 25-percent decrease in synthetic caustic demand from 1990 consumption levels. We also estimate that about ten percent of synthetic caustic would have to be purified further to obtain the qualities required in current high-purity applications.

The net effect of these changes would be to increase soda ash demand by some 13.5 to 14 million tons per year or more, which would require the opening of three to five new mines, depending on the extent to which production from existing mines could be expanded. (3) The most likely scenario for large-scale chemical caustic production would involve soda ash purification at the mine; shipment of dry soda ash to Canada, the Midwest, and the East and Gulf Coasts; and production of liquid caustic there — closer to the markets — to reduce freight costs. Unless markets could be found for more than 12 million tons of calcium carbonate generated in the production of synthetic caustic, which is unlikely, the synthetic caustic soda plants would need large calcining facilities to recover and recycle the lime used in the reaction simply to avoid the generation of enormous amounts of solid wastes. (4) The estimated costs of production of synthetic caustic soda at this scale are summarized in Exhibit 3-3.

Exhibit 3-3. Benefits of Chlorine in Electrolytic Caustic Soda Products (U.S. and Canada)

	Standard Grade	High-Purity Grade
Estimated 1990 consumption[1] (000 tons)	9,000	1,000
Substitute manufacturing process	Treatment of soda ash with calcium hydroxide, calcining for recovery of lime, membrane-based repurification for high-purity grade	
Estimated investment required ($Million)	9,300	1,100
Estimated incremental costs of freight and manufacturing ($Million/Year)	380	50
Estimated total costs of substitution ($Million/Year)	2,240	270

Note:
(1) Consumption in a chlorine-free economy.

SOURCE: Charles River Associates, 1993.

These estimates do not include the infrastructure requirements necessary to support such an undertaking. The new production of soda ash represents a doubling of the current mining activities in the Green River region. The amount of wastes produced, dust and other airborne emissions generated, and water consumed would have noticeable environmental impacts in this region. Material movements would strain existing transportation capabilities because the equivalent of four unit trains (100 rail cars, 10,000 tons hauled) would have to leave the region daily to transport the soda ash to the geographically remote processing plants. The processing plants themselves would be large and energy intensive, and would become centers for the transportation of large amounts of raw material and finished product for distribution to end users.

Price increases for caustic of the order of $250/ton would certainly stimulate attempts to substitute lime or soda ash for synthetic caustic. The net cost of consumers, which are the benefits of chlorine in these applications, would not be reduced greatly, however, because the capital requirements to produce the additional soda ash would be the same as those indicated here, and capital would be required for the solids handling system instead of the synthetic caustic plants. While solids handling systems are simpler than synthetic caustic plants, the diseconomies of scale inherent in the multitude of small systems that would be required would largely offset the increased unit costs of a few larger, more efficient plants.

References

(1) *Riegel's Handbook of Industrial Chemistry*, 9th Ed., J. Kent, ed., Van Nostrand Reinhold, 1992, Chap. 12.

(2) *Kirk-Othmer Encyclopedia of Chemical Technology*, 2nd Ed., J. Wiley & Sons, 1963, Vol. 1.

(3) Personal Communication, D. Kostick, U.S. Bureau of Mines.

(4) "Precipitated Calcium Carbonate Fillers for Paint, Paper and Elastomers," R. Hagemeger, SME Annual Meeting, Atlanta, GA, February 1989.

Potassium Hydroxide (Caustic Potash)

Potassium hydroxide is produced electrolytically from purified solutions of potassium chloride by technology similar to that used in producing sodium hydroxide. Hydrogen and chlorine are generated as coproducts. U.S. and Canadian production of potassium hydroxide from potassium chloride produces about two percent as much chlorine as the electrolysis of sodium chloride produces. The largest single end use for this material is potassium carbonate production. Most carbonate is used to manufacture specialty glasses, including television tubes. The rest is used in applications requiring a mild alkali or for the manufacture of other potassium-containing chemicals. In most cases, potassium hydroxide is used in product manufacture specifically to incorporate the potassium ion, which imparts desirable properties in use. Most clear liquid detergents, for example, are manufactured from potassium hydroxide, while solid detergents are based on sodium hydroxide. (1)

If chlorine production were banned, an alternate process would have to be found for producing potassium hydroxide and its derivatives from available potassium-containing raw materials. The only industrially important minerals available are potassium chloride and potassium sulfate. Technology would have to be developed to exchange the chloride or sulfate anion in potash for another anion (e.g., OH^- or CO_3^{--}) in a cost-effective manner. The only large-scale commercially viable process that has been used to achieve such an exchange is the Solvay process for converting salt to soda ash. (2) This process was abandoned in North America because naturally occurring soda ash can be mined and purified at lower cost, but there is no thermodynamic reason why a *modified* version of the Solvay process could not be used to produce potassium carbonate from potash. (3) We believe only that this product would have to be repurified to produce a grade comparable to that produced electrolytically, and that the potassium hydroxide produced by lime treatment of potassium carbonate would also have to be repurified to meet customer requirements.

We estimate that the costs of converting potassium chloride to potassium carbonate by modifying the Solvay process would be at least 20 percent higher than the costs of a conventional Solvay process because of the more elaborate purification requirements. Since this technology is unproven, and since the plant would be relatively small, costs could be considerably higher. The costs of converting potassium carbonate to potassium hydroxide are assumed to be the same as those required for converting synthetic soda ash to high-purity caustic soda. With these assumptions, the costs of producing "synthetic" potassium salts are shown in Exhibit 3-4.

Exhibit 3-4. Benefits of Chlorine in Electrolytic Potassium Hydroxide Production (U.S. and Canada)

Estimated 1990 consumption (000 tons)	360
Substitute manufacturing process	Treatment of potassium chloride with calcium carbonate in a modified Solvay process, with repurification of potassium carbonate and potassium hydroxide to meet electrolytic grades
Estimated investment required ($Million)	350
Estimated incremental manufacturing costs ($Million/Year)	60
Estimated total costs of substitution ($Million/Year)	130

SOURCE: Charles River Associates, 1993.

Infrastructure requirements to support this technology would be far smaller than those required to produce synthetic caustic soda because the scale of operation would be smaller and freight would be far less of an issue. However, this technology is relatively expensive and raises the question of what to do with the coproduced calcium chloride? In this analysis, we have assumed it could be sold at zero net cost to the process; that is, its sales price would be sufficient to cover the costs of its recovery and purification as well as freight and other distribution costs to sell the product. If these revenues cannot be realized, the costs attributable to producing potassium hydroxide would be higher than shown. If all of the coproduced calcium chloride could not be sold, it would become a waste material that would have to be impounded in waste ponds or perhaps disposed of by deep-well injection. Either approach would increase costs and could raise other environmental concerns.

References

(1) "Chemical Profile — Caustic Potash," *Chemical Marketing Reporter*, October 1, 1990.

(2) *Riegel's Handbook of Industrial Chemistry*, 9th Ed., J. Kent, ed., Van Nostrand Reinhold, 1992, Chap. 12.

(3) *Kirk–Othmer Encyclopedia of Chemical Technology*, 2nd Ed., J. Wiley & Sons, 1963, Vol. 16.

Summary of Benefits

Consumer net benefits from direct chlorine consumption in water disinfection and pulp bleaching and from all uses of coproduced sodium and potassium hydroxides are estimated to be $11.0 billion per year. The estimated capital requirements for the new processes required to produce or use substitute materials amounts to $49.4 billion. The most likely substitute technologies that we have identified are both capital and energy intensive and pose their own environmental and health risks.

Chlorine-Containing Products

Polyvinyl Chloride Products

The making of polyvinyl chloride (PVC) products has been the largest single use for chlorine for many years. In 1990, about 26 percent of chlorine production was required for the manufacture of vinyl chloride monomer (VCM), the immediate precursor to PVC. An additional six percent of chlorine production was required for the manufacture of ethylene dichloride, the immediate precursor of VCM, which was either exported or converted to products other than PVC. PVC resins are produced by polymerizing VCM, and resins with different properties for a variety of end uses can be made by controlling the reaction conditions.. The bulk resins are mixed with various additives that impart specific properties required for fabrication and use. Fabricators can tailor the properties of the resin-additive mixtures to optimize fabrication techniques and product performance properties, and this has resulted in a range of applications for the material that is far broader than for any other plastic. (1)

Consumption of PVC products in all forms amounted to approximately 4.2 million tons in 1990. (2) Some of the consumer products produced from PVC are listed in the chlorine tree shown in Appendix B of this report, but this list is by no means exhaustive. PVC products are produced in either rigid or flexible forms. Flexible products, in use commercially for more than 60 years, were first used as substitutes for natural rubber in wire and cable insulation. They were found to give superior performance in these applications because of their excellent dielectric behavior, flame and moisture resistance, resistance to photo degradation, toughness, and ease of fabrication. Rigid PVC products were introduced commercially some 40 years ago in the United States and Canada and gained rapid acceptance because of their superior properties and ease of use. Many of these products are used in the construction industry for such items as pipe and fittings, flooring, siding, window frames, and other extruded products. Flexible PVC is used for items such as wire and cable insulation, shower curtains, sheeting and liners, and architectural fabrics. Both rigid and flexible products also find widespread use in many industries such as automotive and medical, and in the production of consumer goods such as bottles, wallpaper, packaging, and toys. (3)

In general, PVC products have gained market share in these applications because they offer superior performance at lower costs than the competing materials. In some cases, such as siding, the cost advantage is mainly the result of the lower cost of PVC resin and its ease of fabrication compared with the substitute material. In other cases, such as drain pipe, PVC products provide clear performance advantages and extended service lives compared with competing materials. In still other cases, such as the use of PVC pipe and conduit in building construction, the PVC products are far less expensive to install than either metallic or plastic substitutes. (4) In these and all other applications, PVC products compete with a wide range of products made from various metals, other plastics, glass, wood, concrete, ceramic, and other materials. If chlorine production were banned, and PVC products were no longer available, substitutes would be drawn from each of these materials in specific applications.

To estimate substitution costs, we evaluated information on the current market share of PVC products in each major product area and on the share held by competing materials. In some cases, it was necessary to disaggregate the product end uses further to describe market shares. For example, the major competing material in large diameter pressure water pipe is ductile iron, but in small diameter pipe the competing materials are copper and high-density polyethylene. In other cases, such as plastic bottles, the competing materials depend on the size or contents of the container.

After identifying the substitute materials in each application, we estimated the amounts that would be required to displace PVC in each end use, assuming that the substitute would capture the same market share currently held by PVC. After estimating how much of each substitute material would be required, we estimated the costs of producing and fabricating it into the final product.

In some cases (e.g., aluminum, steel, and certain plastics), ample capacity exists to produce the additional material required, and it can be brought to the market at current prices. In other cases (e.g., ductile iron), additional production capacity would be required, and we estimated the capital requirements necessary to put it in place to produce the final products. In cases where other plastics would be substituted for PVC, we estimated the capital requirements and additional conversion costs (if any) for existing PVC fabricators to switch production to the substitute material. Finally, we estimated the incremental costs of installation for the substitute material in products such as pipe and siding, where substantial c st differences exist between PVC products and their metallic substitutes. Exhibit 3-5 summarizes CRA's analysis of PVC substitution.

These results show that PVC substitution costs are product specific. The highest costs are for substituting large diameter ductile iron (DI) pipe for PVC pipe because new DI pipe production capacity would be required, the DI pipe is more expensive on a purchased price basis per foot installed, and it is more expensive to install as well. Concrete pipe is a somewhat less costly substitute for sewer and drain applications, but using PVC pipe provides performance advantages not captured in this calculation. It is far easier to join and seal PVC pipe reliably, for

Exhibit 3-5. Benefits of Chlorine in PVC Products (U.S. and Canada)

Product Forms	Estimated 1990 Consumption (000 tons)	Substitutes(1)	Estimated Investment Required ($Million)	Estimated Incremental Cost of Substitutes ($Million/Year)	Estimated Total Cost of Substitution ($Million/Year)
Pipe and Fittings					
Pressure water	700	Ductile iron, copper, HDPE	273	1,587	1,642
Sewer/drains	375	Ductile iron, HDPE, RCP	114	590	613
Duct and conduit	285	Aluminum, steel	24	483	487
Drain/waste/vent	300	Ductile iron, ABS	158	774	806
Irrigation	100	HDPE, AL, ABS	36	106	114
Fittings and other	160	From above	55	322	333
Fabricated Products					
Flooring, textiles, and other calendered	515	Ceramics, carpet, nylon, paper, HDPE, PET	147	1,486	1,515
Siding and accessories	410	Aluminum	9	266	267
Wire and cable	230	LDPE, TPO	4	51	51
Windows and other extrusions	305	Aluminum	7	198	199
Adhesives	60	Polyurethanes	0	224	224
Films and sheet	210	LLDPE, HDPE, TPO	88	36	54
Plastic bottles	120	PET-G	0	39	39
Other	430	Miscellaneous plastics	59	535	547
TOTAL	4,200		974	6,697	6,891

(1) HDPE = high-density polyethylene; RCP = reinforced concrete pipe; ABS = acrylonitrile butadiene styrene; PET = polyethylene terephthalate; LDPE = low-density polyethylene; TPO = thermoplastic olefins; LLDPE = linear low-density polyethylene; PET-G = polyethylene terephthalate-G.

SOURCE: Charles River Associates, 1993.

example, and PVC-based systems are not subject to leakage or to picking up infiltrated water that increases loads on water treatment plants. PVC products provide performance advantages in calendered products and coatings that are difficult to replace with other plastics. While uses in these product areas are highly fragmented, we believe that the most likely substitutes across all applications would be more costly per pound than PVC. Significant new investments would be required to produce and fabricate them into the PVC product forms they would substitute for, although we have assumed that all fabricators would remain in business by refurbishing their finishing lines at relatively low cost. If the properties of the substitute material preclude this, costs would be higher than shown, and some fabricators would be forced to shut down.

Producing substitute materials, particularly metals and concrete, is energy intensive and can create other environmental and safety problems. Producing ductile iron requires large amounts of coke (5). Regulations governing allowable emissions in Coke production are currently being implemented because these emissions pose their own risks. In addition, operating steel mills and copper and aluminum smelters also involves significant environmental impacts. (6,7) Substituting thermoplastic olefinic materials like low-density polyethylene for PVC in electrical uses would, at minimum, require revision of existing codes and would raise safety issues because these substitutes do not have PVC's fire resistance. Our estimates do not include the costs of making the changes in building codes and other regulations that would be required if PVC products were not available.

References

(1) *Engineered Materials Handbook, Vol. 2 — Engineering Plastics*, ASM International, 1988, p. 209.

(2) "Resins 1992: Supply Patterns are Changing," *Modern Plastics*, January 1992, p. 53.

(3) "PVC and the Environment," N. Kansvog and J. Baldwin, Norsk Hydro a.s., Petrochemical Division, Oslo, Norway, 1992.

(4) *A Cost/Benefit Study: In-Place Costs and Technical and Regulatory Constraints to Use of PVC-Based Pipe, Tube, and Conduit in Construction*, IFT Technical Services, Berkeley, CA, 1989.

(5) "Konzeption einer Modernen Heisswind–Kupolofenanlage," E. Freunscht and A. Rudolph, *Giesseri* 76, No. 10/11, 1989, p. 328.
(6) *Coke Oven Emissions from Wet-Coal Charged By-Product Coke Oven Batteries — Background Information for Proposed Standards*. United States Environmental Protection Agency EPA-450/3-85-028a, April 1987.
(7) "Impact of 1990 Clean Air Act Amendments on the Iron and Steel Industry," B. Steiner, *Iron and Steel Engineer*, January 1992, p. 41.

Chlorinated Solvents

Chlorinated solvents include, as a class, compounds containing carbon, hydrogen, chlorine, and in some cases fluorine. Some of these compounds are being phased out under the Montreal Protocols of 1987 and subsequent amendments, and they are not considered in this analysis. Other solvents in this class, methyl chloride and chloroform in particular, are consumed as feedstocks mainly in the manufacture of other compounds. These uses are not banned, and consumption of these solvents is described in our discussion of the products made from them.

The compounds considered here — methylene chloride, trichloroethylene, trichloroethane, and perchloroethylene — are used as solvents in a variety of processes. Increased costs for waste treatment and disposal have led some users to seek alternate manufacturing processes that do not use these materials. Concerns for the possible environmental effects of the release of these solvents have led other users to improve operating practices to reduce processing losses, and consumption has fallen in recent years. Some substitution has already taken place, but these solvents have retained markets in many applications because of their desirable properties: they are stable, nonflammable, have relatively low boiling points, and are powerful solvents for a wide variety of materials. These properties permit them to be used in relatively simple, easy-to-maintain and operate equipment that can be found in more than 50,000 establishments in the United States and Canada. (1,2)

Most neighborhood dry-cleaning establishments clean items that cannot be washed in water by exposing them to perchloroethylene, which removes the stains and soil. The residual solvent is removed from the goods by evaporation at low temperatures and is then recovered and recycled. Dirty solvent is sent to central solvent recovery operations for recovery and recycling. Perchloroethylene is a particularly attractive solvent for this application because it is nonflammable, has a low boiling point, and does not damage most materials or synthetic fibers.

Large, centralized laundries and dry cleaners may use other solvents, particularly hydrocarbon materials called Stoddard solvent. (1) Hydrocarbon solvents are less expensive than perchloroethylene, and so replacement costs for solvent lost through evaporation are lower. However, Stoddard solvent is flammable, and equipment and facilities must be specially designed to prevent fire or explosion. This is easier to accomplish in large facilities than in small ones, although it is technically possible at any scale. While "dry-cleaning" technologies based on the use of small amounts of water are being investigated now, they may not be feasible or effective for the care of all fabrics. (3) We believe, therefore, that the most likely substitute for perchloroethylene in dry cleaning would be Stoddard solvent. Switching to this solvent would require the small dry-cleaning establishments to replace their existing equipment with new equipment designed for the flammable solvent.

All of the solvents considered here are used in a wide range of industrial processes to clean parts in manufacture. There are three major cleaning processes in use: processes in which parts are exposed to solvent vapors; processes in which parts are exposed to liquid solvents in a carefully controlled fashion; and processes in which parts are "cold cleaned," usually simply by wiping them. There are tens of thousands of vapor degreasers in use in various manufacturing operations, and an uncounted number of cold-cleaning operations. There are fewer operations in which "special parts" are cleaned; these systems tend to be used where a large volume of identical parts are being produced (as in the manufacture of automotive components), or where the parts have very high value (as in the electronics industry). (2)

In many cases, hydrocarbon solvents — including Stoddard solvent — would be substituted for chlorinated ones in vapor degreasing and cold-cleaning applications. As is the case with dry cleaning, equipment replacement or modifications would be required because the hydrocarbons are flammable. Simply covering the degreasers to control emissions would decrease productivity and would not be responsive to the requirements of existing codes. In other cases, such substitution would not be possible for technical or economic reasons: solvent and parts might not be compatible, the solvents would not provide sufficient cleaning, or modification of the existing degreasing equipment would be infeasible or too costly. A manufacturer faced with these problems has three choices: 1) alter the manufacturing process to eliminate the cause of the contamination that led to the need to use solvents for cleaning, 2) adapt the manufacturing process for use with hydrocarbon solvents, or 3) adopt more complex aqueous or semiaqueous cleaning processes.

Aqueous processes have been developed recently to substitute for banned solvents in the electronics and other industries. (4) These processes can be highly effective. But they are capital intensive and complicated, and, in the event of a chlorine ban, would be used if simpler approaches were not feasible. We estimate that no more than a few thousand of these systems would be installed. Altering or adapting the manufacturing process would be considered if such changes could be made at a reasonable cost. For example, substitution of aqueous-based coolants for oil-based ones in certain machining operators might permit aqueous-based cleaning systems to be used effectively. The increased cost for the coolant and for the aqueous cleaning system could be lower than the costs of modifying a degreaser, although use of aqueous coolants might not be feasible for all alloys or all metalworking operations.

Chlorinated solvents, particularly methylene chloride, are also used as selective solvents for a variety of adhesives and other materials. Methylene chloride is also used as a paint stripper. (5,6) In most cases, high-volatility hydrocarbon-based or oxygenated solvents could be substituted for the chlorinated ones in paint stripping and some solvent applications, although some performance loss would occur. Since many of these substitutes are less expensive than chlorinated solvents, they would already be in use if their performance were comparable.

Where chlorinated solvents are used as process solvents or extractants, as is the case with methylene chloride use in manufacturing pharmaceuticals and photographic film, major equipment and process changes would be required because of the great differences in solubility and boiling points between chlorinated and nonchlorinated materials. (7) Such changes would be extremely capital intensive because of the large amounts of solvents in circulation through the processes. Existing solvent recovery systems typically capture and recycle from 95 to more than 99 percent of the materials processed, so that the consumption reported to offset losses represent only 1 to 5 percent of the total in circulation. Furthermore, solvent recovery techniques are more difficult and costly for many substitutes, and equipment must be designed to explosion-proof standards as well. The estimated costs and techniques that would be required to substitute for chlorinated solvents are summarized in Exhibit 3-6.

Exhibit 3-6. Benefits of Chlorine in Chlorinated Solvents (U.S. and Canada)

Applications (Solvents)[1]	Estimated [illegible] Consumption (000 tons)	Estimated Substitution	Estimated Investment Required ($Million)	Estimated Incremental Cost of Substitutes[2] ($Million/Year)	Estimated Total Cost of Substitution ($Million/Year)
Dry cleaning (PERC)	72	Stoddard solvent systems	4,600	(40)	880
Vapor degreasing and cold cleaning (TCA, TCE, PERC)	330	Aqueous-based cleaning systems; non-halogenated solvent-based systems; altered manufacturing processes	580	(76)	40
Special parts cleaning (TCA, TCE, PERC, METH)	75	Semiaqueous cleaning processes; altered manufacturing processes	300	60	120
Paint stripping, adhesives, and other uses (METH)	57	Hydrocarbon-based materials or oxygenated solvents	–	20	20
Process solvent or extractant (METH)	29	Various, process specific	1,160	58	290
Total			6,640	22	1,350

Notes:

(1) PERC = perchloroethylene; TCA = 1,1,1-trichloroethane; TCE = trichloroethylene; METH = methylene chloride.

(2) Figures in parenthesis indicate applications where use of substitute materials or processes would result in cost savings vis-à-vis use of chlorinated solvents.

SOURCE: Charles River Associates, 1993.

The major impacts of banning chlorinated solvents would be borne by local dry-cleaning operators. Solvent consumption costs would decrease because Stoddard solvent is less expensive than perchlorethylene, and solvent losses would have to be reduced for safety reasons. However, operators would be forced to purchase equipment designed to function with flammable solvents. We estimate that these costs would exceed $50,000 for small, single-machine establishments, a sum that may exceed their cashflows for some years. We assume in this analysis that local codes would permit dry cleaners to use flammable solvents, but these substitutes are dangerous and present definite safety hazards, particularly in multiple-occupancy buildings.

Similar tradeoffs would be made in industrial vapor degreasing and special parts cleaning systems. In these cases, we also expect some productivity loss because the replacement equipment is more complex to operate. Safety issues would be of less concern in a well-designed and properly maintained industrial environment. However, no system can be designed and operated in such a way that there are *no* losses of the working solvents, and some of the solvents that might be substituted for chlorinated ones have been implicated in the formation of photochemical smogs.

References

(1) *Source Reduction and Recycling of Halogenated Solvents in the Dry Cleaning Industry — Technical Support Document*, Jacobs Engineering Group Ltd., Pasadena, CA, 1992.
(2) *Source Reduction and Recycling of Halogenated Solvents in Parts Cleaning — Technical Support Document*, Jacobs Engineering Group Ltd., Pasadena, CA, 1992.
(3) "EPA to Look at the Suitability of 'Wet' Method in Hopes of Cutting PCE Output," M. Habiby, *Wall Street Journal*, November 16, 1992.
(4) *Aqueous Cleaning as an Alternative to CFC and Chlorinated Solvent-Based Cleaning*, C. D'Ruiz, Noyes Publications, 1991.
(5) *Source Reductions and Recycling of Halogenated Solvents in the Adhesives Industry — Technical Support Document*, Jacobs, Engineering Group Ltd., Pasadena, CA, 1992.
(6) *Source Reductions and Recycling of Halogenated Solvents in Paint Stripping — Technical Support Document*, Jacobs Engineering Group Ltd., Pasadena, CA, 1992.
(7) *Source Reductions and Recycling of Halogenated Solvents in the Pharmaceutical Industry — Technical Support Document*, Jacobs Engineering Group Ltd., Pasadena, CA, 1992.

Hydrogen Chloride (Hydrochloric Acid)

Large amounts of hydrogen chloride are produced as a byproduct of the manufacture of other chlorinated compounds, particularly vinyl chloride monomer (VCM), chlorofluorocarbons, chloromethanes, and isocyanates. Most of the byproduct production of VCM manufacture is recycled for the production of ethylene dichloride, and the balance of the byproduct material is either sold or neutralized and disposed. About ten percent of the merchant requirements for hydrogen chloride are supplied by so-called "burner acid," material made "on purpose" by the reaction of elemental chlorine with hydrogen. (1) Because most hydrogen chloride is produced as a byproduct of a number of processes and because most individual uses are small, particularly in water treatment, estimates of consumption can differ widely.

Hydrogen chloride is a gas, but it is normally used as an aqueous solution of hydrochloric acid, also known as muriatic acid. It is a strong acid and is used in a variety of applications such as metal cleaning, food processing, oil well acidulation, water treatment, and the manufacture of inorganic chloride salts. (2) Except for the latter use, it competes with other strong acids such as nitric and sulfuric acids on the basis of delivered price and performance in the application. Most customers rely on regional acid suppliers, and transportation costs are often a significant portion of the delivered price. The major suppliers of byproduct sulfuric acid are smelters located in the West. There is ample production capacity to supply sulfuric acid in those applications where it could displace hydrochloric acid, but new capacity would be required to produce significant amounts of additional nitric acid, which is produced "on purpose" by the oxidation of ammonia.

Large amounts of hydrochloric acid are used in steel production to "pickle" or clean the finished products. (3) This produces a spent acid solution containing iron chlorides. The solution may be neutralized and disposed, regenerated to produce hydrogen chloride for recycling, or treated to recover the iron chlorides for sale. Acid-free steel-cleaning technologies based on mechanical processes such as shot blasting have not been generally accepted; the most likely alternative to hydrochloric acid for pickling is sulfuric acid, which is not in widespread use because of the cost and difficulty of recovering the spent acid solutions. Sulfuric acid recovery systems have been operated in specialty steel plants, which may use mixed acids for pickling, under conditions where their costs are offset by reductions in the cost of landfilling neutralized acid wastes. Such techniques could also be used in pickling low-carbon steels, with existing equipment replaced by equipment designed to use and recover sulfuric acid.

Hydrochloric acid is also used by the food industries. The manufacture of high-fructose corn syrup and artificial sweeteners is the main source of consumption. (4) Either nitric or sulfuric acids might be substituted in these applications, although the use of byproduct smelter acid might be limited in some applications by Food Chemical Codex requirements. Sulfuric acid now competes with hydrochloric acid in this industry based on delivered price, and holds significant market share for such applications as ion-exchange regeneration. On this basis, we estimate that smelter acid would capture all uses not limited by Codex and that the higher-priced nitric acid would capture the rest.

Both nitric and sulfuric acid could substitute for hydrochloric acid in water treatment uses, which include both pH adjustment and ion-exchange regeneration. (5) Since there are no acid purity limitations in these applications, the lower-priced sulfuric acid should capture most of the market share. In some cases, equipment changes could be required in water treatment systems switching to sulfuric acid because the sulfate salts produced by neutralization would be insoluble and might have to be removed by sedimentation or filtration. Such costs would be borne if the capital charges and other operating costs were lower than nitric acid's incremental cost.

This flexibility would not exist in oil well acidulation, where hydrochloric acid is used to stimulate production by fracturing limestone and other carbonate formations. Sulfuric acid, forming insoluble salts, is not likely to be as effective in changing permeability, and we believe that nitric acid is the more likely general substitute for these applications. The estimated costs incurred by the need to substitute for hydrochloric acid are summarized in Exhibit 3-7.

Exhibit 3-7. Benefits of Chlorine in Hydrochloric Acid (U.S. and Canada)

Applications	Estimated 1990[1] Consumption (000 tons)	Substitutes	Estimated Investment Required ($Million)	Estimated Incremental Cost of Substitutes ($Million/Year)	Estimated Total Cost of Substitution ($Million/Year)
Steel pickling	270	Sulfuric acid	1,000	100	300
Food processing	180	Nitric acid, sulfuric acid	10	30	32
Oil well acidulation	190	Nitric acid	20	60	64
Water treatment and other uses	340	Sulfuric acid, nitric acid	20	60	64

Note:

(1) Estimated total consumption and breakdown is based on data from various sources.

SOURCE: Charles River Associates, 1993.

The major capital requirements for hydrogen chloride substitution are for modifying pickling lines and installing special acid recovery systems in the steel industry. Capital requirements could be reduced if acid regeneration were not practiced, but this would both increase consumption of make-up acid and create large amounts of solid wastes that would have to be disposed of by landfilling. Steelmakers could continue to use existing hydrochloric acid-based pickling limes and avoid these investments if they were willing to satisfy their make-up chloride requirements by using technology based on the treatment of sodium chloride with sulfur dioxide or sulfuric acid. Small amounts, about 25,000 tons per year, of hydrogen chloride are currently coproduced by this method in the manufacture of saltcake. While technically feasible, such an approach would probably not be attractive because the small saltcake manufacturing plants would be relatively costly, the processes can be difficult to operate, creating their own environmental problems, and sale or disposal of the saltcake would be troublesome.

The steel industry alone would produce about two thirds of the current domestic requirements for saltcake, so that the market for this product would be disrupted, and the excess material would have to be disposed of. In the absence of byproduct saltcake credits, manufacturing costs for hydrogen chloride could increase to the level at which this option would not be viable for any of the other uses, and it is unlikely that it could complete with direct substitution of sulfuric acid under almost any circumstances.

When hydrochloric acid is used in water treatment, it is ultimately converted to a soluble chloride. We have not included allowances in these estimates either for removal of any insoluble sulfate salts that might be formed if sulfuric acid were substituted or for removal of nitrates if nitric acid were substituted for hydrochloric acid in water treatment. Both sulfates and nitrates can create environmental problems under some circumstances, and the manufacture of nitric acid results in significant emission of NO_x from the production plant tail gases.

References

(1) "HCl Faces Bleak Future: Oversupply Plagues Industry," *Chemical Marketing Reporter*, July 16, 1990.
(2) "HCl Opportunities Wane as Acid Supplies Advance," G. Busch, *Chemical Marketing Reporter*, August 26, 1991.
(3) *The Making, Shaping and Treating of Steel*, 10th Ed., United States Steel, Herbigk and Held, Chap. 25.
(4) "Hydrochloric Acid in the 90s: Clear Sailing or Time to Bail Out?" G. Henderson, *Proceedings of the CMRA*, New York, NY, May 1992, p. 285.
(5) "Sulfuric Acid: A New Threat?," *Sulfur*, No. 211, Nov–Dec 1990, p. 17.

Bleaches, Disinfectants, and Pool Chemicals

Products containing sodium and calcium hypochlorites, which are made by the addition of chlorine to solutions of sodium and calcium hydroxide, are well-known to consumers in their uses as household laundry bleaches and swimming pool treatment chemicals. They are also used in a variety of institutional and industrial applications because of their properties as bleaches, disinfectants, and sanitizers.

The largest single use of sodium hypochlorite is as a household laundry bleach, and it currently holds about 90 percent of the market for these products. (1) The remaining market share is held by various peroxy compounds, principally sodium perborate and peracid compounds. Hypochlorites are favored in these applications because they are low cost, easy to use, and are effective at all water temperatures and hardnesses against a wide variety of stains. If chlorine production were banned, formulations containing perborates could be substituted for hypochlorites, with some differences in performance. Perborates are not effective at the low water temperatures favored by U.S. and Canadian consumers unless they are "promoted" by adding various activating chemicals. (2) If these types of bleach formulations are not found to be acceptable, it is likely that detergent formulations would also have to be adjusted to achieve better performance from the enzymes, brighteners, and surfactants that they contain. The possible costs of these changes are not considered in this analysis, but the costs of expanding perborate and "promoter" production capacity are included.

Sodium hypochlorite is an inexpensive material because the starting materials are low-cost commodities and the production process is extremely simple. Producing peroxy chemicals, on the other hand, involves far more complex technology and is energy and capital intensive. Also, additional production capacity would be required for the "promoters," which are used at levels ranging from about 40 to 100 percent of perborate concentration. These "promoters" are also complex compounds (e.g., tetraacetylethylene diamine (TAED), or sodium nonanoyloxybenzene sulfonate (SNOBS)), with high capital requirements and production costs in their manufacture.

Both sodium and calcium hypochlorites are used as disinfectants and sanitizers in residential and institutional swimming pools. They hold a large market share but compete with other compounds such as trichloroisocyanuric acid, various brominated compounds, and other proprietary formulations based on ease of use and application. (3) Chlorinated or brominated compounds could not be considered substitutes under conditions where chlorine is banned, but some of the chlorine-free formulations could be considered unless they have been synthesized using chlorine-containing intermediates. We know little about these formulations, except that at current prices they are on the order of five times as expensive on a retail basis as hypochlorites. We assume that large production capacity increases will be required if these materials replace the hypochlorites, with the attendant large investment requirements, but that the economies of scale associated with increased production will drop their price by a factor of at least two.

The major remaining hypochlorite applications are disinfectants and hard surface cleaners in food processing, hospitals, restaurants, and other institutions. The peroxy compounds used in bleaching or pool chemicals would not be effective in these applications, and the most likely substitute material is hydrogen peroxide. The substitution ratio required is not clear, but on a stoichiometric basis it would be on the order of one half pound of peroxide per pound of hypochlorite. Based on these assumptions, the estimated costs to substitute for hypochlorites in these applications are summarized in Exhibit 3-8.

Exhibit 3-8. Benefits of Chlorine in Bleaching, Disinfectant, and Pool Chemicals[1] (U.S. and Canada)

Estimated 1990 hypochlorites consumption (000 tons)	377
Substitutes	Perborates with promoters, hydrogen peroxide, and other specialty chemicals
Estimated investment required ($Million)	650
Estimated incremental cost of substitutes ($Million/Year)	670
Estimated total cost of substitution ($Million/Year)	800

Note:

(1) Excludes consumption of chlorinated isocyanurates and other chlorine-based pool chemicals.

SOURCE: Charles River Associates, 1993.

In making these estimates, we have assumed that consumers will use higher-temperature water for laundering so that perborate bleaches will be effective with low concentrations of promoters, although we have not estimated the increased energy costs to heat the water. If consumers continue to demand products that are effective at low water temperatures, both investment requirements and the net costs of substitution will exceed $1 billion because two or three times as much of the expensive promoters will be required. As an alternate to this practice, stronger bleaching agents might be substituted — potassium monopersulfate (oxime), for example — but these compounds can cause damage to certain dyed fabrics. The public health benefits of using hypochlorites as pool sanitizers and disinfectants are evident. Hydrogen peroxide could be equally effective, although more costly as a disinfectant, but the large-scale application of chlorine-free chemicals as swimming pool sanitizing agents is untested.

References

(1) "The Ultra Show," A. Naude, *Chemical Marketing Reporter*, January 27, 1992.

(2) "Warwick Sees Strong Potential for TAED in U.S.," *Chemical Marketing Reporter*, June 22, 1992.

(3) "Isocyanurates Perform Well in Sanitizers Market," *Chemical Marketing Reporter*, November 6, 1989, p. 41.

Polychloroprene Products

Polychloroprene products, perhaps best known to consumers through products bearing the tradename Neoprene®, are based on synthetic rubbers made by polymerizing the monomer 2-chloro-1,3-butadiene. (1) While the production processes and raw materials for this material have changed over the years, and many new competing elastomers have been developed, polychloroprene still finds widespread use in applications that it has held for more than 60 years. Major products include electrical insulation and sheathing material, sealing materials, conveyor belts and power transmission belts, flexible bellows and hoses. Adhesive grades of polychloroprene are used in footwear, and polychloroprene latexes are used in manufacturing foams, fiber binders, carpet backings, gloves and protective wear, and adhesives. (2) Polychloroprene has excellent physical properties and resistance to weathering, ozone, and oil. Its excellent heat and oil resistance and its high modulus and recovery factor have contributed to the market share held by polychloroprene in under-the-hood automotive operations. (3) This market position has been largely unchallenged since the material was first introduced in these applications.

Of the available, large-volume elastomers that might substitute for polychloroprene, nitrile butadiene rubber would have the best oil resistance and reasonable mechanical properties, and so could be used for belts and conveyors for electrical uses and some other applications. It has poor heat resistance, however, and so would have shorter life in under-the-hood applications. For applications that do not require low hysteresis loss, copolyester resins and olefinic thermoplastic vulcanates could provide reasonable heat and oil resistance. Both of these materials are more costly than chloroprene, and new manufacturing capacity would be required because their higher cost limits their current market. While these materials have better mechanical properties and heat and oil resistance than most other elastomers, they are inferior to polychloroprene, and we estimate that their service lives in some applications will be half that of the products they are assumed to replace. With these assumptions, the estimated costs of substitution are summarized in Exhibit 3-9.

Exhibit 3-9. Benefits of Chlorine in Polychloroprene Products (U.S. and Canada)

Estimated 1990 chloroprene consumption (000 tons)	87
Substitute	NBR in less demanding applications; COPE and OTPV in more demanding ones[1]
Estimated investment required ($Million)	200
Estimated incremental cost of substitutes ($Million/Year)	340
Estimated total cost of substitution ($Million/Year)	380

Note:

(1) NBR = nitrile butadiene rubber; COPE = copolyester resins; and OTPV = olefinic thermoplastic vulcanates.

SOURCE: Charles River Associates, 1993.

Estimating benefits for this class of products is difficult because none of the available substitutes can match all of polychloroprene's properties. Therefore, some performance loss must be expected regardless of the substitute's price. Shorter service lives will impose additional costs on consumers for maintenance and repair that are not captured in these estimates.

References

(1) *Ullmann's Encyclopedia of Industrial Chemistry* 5th Ed., W. Gerhartz ed., VCH Publishing, Vol. A13.

(2) "Chemical Profile — Polychloroprene," *Chemical Marketing Reporter*, May 13, 1991.

(3) "Follow That Car: Nitrile, Butyl and Polychloroprene are Taking Their Lumps With Slow Auto Sales," K. Topfer, *Chemical Marketing Reporter*, October 28, 1991.

Crop Protection Chemicals

Crop protection chemicals include herbicides, fungicides, insecticides, and other chemicals that are used by the agricultural industry to reduce crop losses, improve yields, and produce higher-quality products for consumers at the lowest possible cost. Compounds in this class are also used directly by consumers at home for pest and weed control. As we will show, most of these products either contain chlorine or chlorine is used in their manufacture, and it is not clear that chlorine-free substitutes can be developed for many of them. For this analysis, we have assumed that non-agricultural consumers will either use available chlorine-free materials or forgo consumption of no longer available ones at no economic cost. All of the benefits we will estimate will arise from the current use of these materials in agriculture.

The earliest general uses of some of these materials involved their widespread uses at high applications rates. It was later recognized that these practices had adverse environmental impacts, and this resulted in severe restrictions on their use. A number of heavily chlorinated insecticides, such as DDT, and other pesticides have been banned, and the use of others has been restricted by regulatory actions. The consequences of using still others are currently under review because of concerns over the possible migration of toxic materials in agricultural runoff and their potential impact on private and public water supplies, human health, and wildlife.

In spite of the potential adverse effects associated with their use, it is generally recognized that using crop protection chemicals has resulted in tremendous gains in agricultural efficiency in the United States and Canada. This has produced very significant benefits to consumers in the form of food prices that are lower than would be possible using alternative farming techniques. As we will show, a ban on chlorine production would affect far more than the manufacture of those chemicals that contain chlorine. Because of the importance of chlorine chemistry in the agricultural area, and because of the magnitude of the benefits that we attribute to chlorine, the methodology we use to estimate the benefits of crop protection chemicals is presented here in some detail.

Regulatory pressures to restrict or ban the use of certain crop protection chemicals, particularly those containing chlorine, have been exerted with varying degrees of intensity for 30 years. Over this period, a number of less persistent, less heavily chlorinated materials have been developed and have replaced those that have been restricted or banned. This should have been time enough for the industry to complete research, development, testing, and registration activities on new generations of crop protection chemicals that do not contain chlorine on the molecule, or involve chlorine chemistry in their manufacture. However, as we will show, almost all crop protection chemicals are still based on chlorine chemistry. To the extent that it has not been possible to develop low-cost alternatives to chlorine-based materials in the last 30 years, there is little reason to believe that future R&D efforts will be significantly more successful. A ban on chlorine production would require either changes in agricultural practices that now depend on chlorine-based materials or the use of yet-to-be-developed, more costly materials that are synthesized by alternate routes. It is not clear that the impacts of such a ban would be alleviated by other changes in agricultural technology such as the use of genetically engineering plants. (1)

To determine the importance of chlorine chemistry in manufacturing crop protection chemicals, we surveyed the sales of each type to ascertain the identity of the most important products. (2) Then, based on information in the patent literature and other information, we determined whether chlorine chemistry was involved in their manufacture as intermediates or as process solvents. (3) The results of this survey are summarized in Exhibit 3-10.

Exhibit 3-10. Chlorine Chemistry in the Manufacture of Crop Protection Chemicals

Type of Chemical	Total Bulk Sales in [illegible] ($Million)	Percent of Sales Surveyed	Percent of Surveyed Chemicals Sales With		
			Cl_2 in Molecule	Cl_2 in Manufacture	No Cl_2 Involved
Herbicides	3,400	83.5	59.9	40.1	0
Fungicides	455	94.5	52.3	44.0	3.7
Insecticides	1,290	87.2	39.6	47.6	12.8
Others	315	70.1	61.5	23.1	15.4
Totals	5,460	84.6	54.3	41.5	4.2

SOURCE: Charles River Associates, 1993, based on (1) and (2).

This summary shows that, while just over half of the sales of surveyed chemicals have chlorine in the active compound, almost 96 percent involve chlorine chemistry in their manufacture. Thus, banning chlorine production is equivalent to banning herbicide production and reducing the production of the other crop protection chemicals to the point where severe crop losses would be expected.

The economic impact of banning crop protection chemicals has been analyzed by others. In a large scale and well-designed study conducted by Taylor et al. (4), a regional econometric model of U.S. agriculture was developed that included eight major crops and nine livestock categories. The model was used to evaluate the impact on crop yields, production, consumption, inventories, agriculture prices, and foreign trade of various regulatory options, including a *complete* ban on the use of crop protection chemicals. It is regionally specific, and considers how other production factors like land use, farm equipment, labor, and fertilizers might be used more intensively to compensate for the banning of crop protection chemicals.

Taylor's results indicate that U.S. consumers in these crop and livestock categories would lose $14.7 billion per year from a ban only on herbicides, and $17.5 billion per year from a total ban of all crop protection chemicals. Since Taylor's model does not account for the entire agricultural economy, but only the major cash crops and livestock, these estimates understate the total cost to consumers. Furthermore, Taylor's model did not consider the economic losses for Canadian consumers.

To estimate the impact on Canadian agriculture, CRA reviewed data on the distribution of farm income by source for the United States and Canada in 1990. (5,6) As indicated above, Taylor's model covered 17 sources of farm income: eight major crops and nine livestock categories. For these products, farm income in Canada amounted to 9.8 percent of the U.S. farm income. Assuming that the relationships between crop protection chemicals, farming practices, and the economy are similar between the United States and Canada, the cost to consumers of a chlorine ban for these 17 sectors of the agricultural economy in Canada is estimated to be $1.7 billion per year.

The Taylor model did not consider many other sectors of the agricultural economy — fruits and nuts, vegetables, and poultry, for example. The value of these additional sectors of crops and livestock in the United States and Canada amounted to $41.6 billion in 1990. In order to estimate the economic impact of a chlorine ban on these sectors, we made the following assumptions: 1) the usage pattern for crop protection chemicals is the same in the United States and Canada; 2) the sales distribution of crop protection chemicals as shown in Exhibit 3-10 is the same in the United States and Canada; 3) a ban on chlorine reduces sales of these chemicals to 4.2 percent of their value in 1990 (that is, 95.8 percent of these chemicals are eliminated from the farm economy); and 4) sales of crop protection chemicals amounted to 3.2 percent of the total value of factor inputs to the agricultural economy in the United States and Canada.

Using the Cobb–Douglas production model (see Appendix A for a description), CRA estimated the economic impact of a chlorine ban on those sectors of the farm economy not captured by the Taylor model. This model is useful for estimating how farmers are willing to employ other production factors (like additional land, farm equipment, labor, and fertilizers) in order to maintain their previous level of farm output. In this case, the Cobb–Douglas model shows that the net costs of the other production factors must increase by $4.8 billion.

CRA estimates that the total consumer benefits of crop protection chemicals in the United States and Canada, therefore, amount to the following sums:

Consumer benefits (U.S.), 17 sectors	$17.5 billion per year
Consumer benefits (Can.), 17 sectors	$1.7 billion per year
Consumer benefits (U.S., Can.), other sectors	$4.8 billion per year
Total Consumers benefits	$24.0 billion per year

Neither the Taylor model nor the Cobb–Douglas model lead directly to estimates of the new investments that would be required for new farm equipment and machinery. It is clear that some new equipment would be required, since more land — and generally land of poorer quality — would have to be farmed to maintain the same production at lower yields. Yield losses for four of the modeled crops have been estimated to range from 20 percent (wheat) to 70 percent (cotton) as a consequence of such a ban (7), and it would require the cultivation of tens of millions of additional acres to offset yield losses in all crops affected.

In 1990, the value of farm implements and machinery in the United States was $91.7 billion, and farmers' expenditures for new vehicles and equipment was $13.6 billion. (5) The amount of acreage planted would have to increase by about ten percent (4), and we assume that farmers would make a one-time increase in their normal level purchases of new equipment to create a sufficient stock to work the additional land. ·We estimate that these expenditures would amount to about 1.5 percent of the existing stock of equipment, or about ten percent of the normal purchases of new equipment, and would total about $1.5 billion in the United

States and Canada. Our estimates of the net costs of banning chlorine use in crop protection chemicals are summarized in Exhibit 3-11.

Exhibit 3-11. Benefits of Chlorine Chemistry in Crop Protection Chemicals (U.S. and Canada)

Estimated 1990 consumption (000 tons)	467
Substitute	Modified farming practices
Estimated investment required ($Million)	1,500
Estimated incremental cost of substitute ($Million/Year)	24,000
Estimated total cost of substitution ($Million/Year)	24,300

SOURCE: Charles River Associates, 1993.

The total sales of crop protection chemicals in the agricultural economies of the United States and Canada in 1990 were about $6.3 billion, so that these estimates indicate that they generate $4 of benefits to consumers for every $1 of sales, a significant multiplier. If this same multiplier applied to sales for home and garden uses, an additional $9 billion per year in benefits would accrue to consumers where we have not attributed any costs of substitution. About 80 percent of the estimated benefits were calculated from a very complex econometric model of all of the significant factors of farm production. (4) These results contradict the belief that alternative agricultural practices such as better crop rotation and mixing, use of natural predators and "natural" pesticide chemicals, etc., would increase farm productivity and yields and decrease costs for all farmers. (8) Taylor's model attempts to determine the outcome of the interplay between the production factors through a complex mathematical description of this relationship that is rather abstract. On the other hand, estimates that costs could be *reduced* by a ban on crop protection chemicals are not supported by any such model of the farm economy.

As a cross-check of the conclusions that costs would *increase* by more than $24 billion, we applied the Cobb–Douglas model in its simplest form for all crop protection chemicals against the total value of the U.S. and Canadian agricultural economies. Using this model we estimate that the net cost of substitution would be over $14 billion, which confirms the order of magnitude of the benefits of chlorine chemistry in crop protection chemicals estimated by Taylor's model. The Cobb–Douglas model cannot be used in a more complex form, breaking out the individual components of crop protection chemicals, because it would predict infinite costs of substitution for herbicides, which would be removed completely as a production factor. The slightly lower estimate that results from the simplified Cobb–Douglas model is consistent with the underestimation of the benefits of herbicides.

The increased costs of alternate farming methods of this magnitude would be apparent to consumers immediately in the form of higher prices for grain-based food staples, fruit, produce, meat, poultry, eggs, and milk. These costs would not be distributed evenly throughout the economy, but would be borne most heavily by those with the least ability to pay. In the longer term, more intensive farming of lower-quality land may lead to further drawdowns of scarce water resources in some regions and increased soil losses to erosion. These practices would also introduce more instability in farm commodity prices because it would be more difficult to cope with the occasional severe fluctuation in yields that are weather- and pest outbreak-related. The increased production costs would also decrease the competitiveness of U.S. and Canadian farmers in world markets, reducing the positive balance of trade now enjoyed in agricultural products.

References

(1) "Herbicide-Resistant Crops Focus of Biotechnology Debate," R. Bauer, *Chemical and Engineering News*, March 18, 1993, p. 38.

(2) Personal Communications, D. MacIver and E. Callies, Consultants.

(3) *Pesticide Manufacturing and Toxic Materials Control Encyclopedia*, M. Sittig, Noyes Data Corp., 1980.

(4) "Economic Impacts of Chemical Use Reduction on the South," C. Taylor et al., *Southern Journal of Agricultural Economics*, July 1991, p. 15.

(5) *Statistical Abstract of the United States*, 112th Ed., U.S. Department of Commerce, 1992.

(6) *Canadian Economic Observer, Historical Supplement, 1991/92*, Ministry of Industry, Science, and Technology, 1992.
(7) "The Value of Crop Protection Chemicals to American Agriculture and the Consumer," *GRC Economics*, 1990.
(8) *Alternative Agriculture*, National Research Council, National Academy of Sciences, 1989.

Flame Retardants

As a class, flame retardants include a wide range of inorganic and organic compounds that are added to plastics and textiles to modify and improve their performance. (1) These compounds reduce flammability by delaying the onset of combustion, decreasing the rate of combustion, promoting self-extinction, preventing reignition, and inhibiting smoke formation. Chlorine-free compounds, mainly alumina trihydrate, magnesium hydroxide, various phosphate esters and compounds, borates, and antimony compounds have the largest share of the flame retardant markets. They are generally available at lower cost than chlorine-derived materials, although some need to be added at higher loadings to achieve comparable performance. Where chlorinated or brominated compounds are used, they provide performance advantages that justify their higher price, and finding acceptable substitute materials is not simple.

Organobromine compounds based on hydrocarbons or oxygenated chemicals have the second largest share of flame retardants. Bromine and brominated compounds would have to be substituted for since commercial bromine production consumes chlorine. Brominated materials are usually used together with other compounds, such as antimony oxides, that promote performance and allow them to be used at lower concentrations. This not only reduces costs, but permits them to be used in applications where additions of larger amounts of less effective flame retardants would degrade the product's mechanical properties or performance. Chlorinated hydrocarbons and chlorinated organophosphorus compounds provide the same type of functionality as brominated compounds, with the higher-cost phosphate ester compounds serving a dual role as plasticizers in some resins, and the lower-cost chlorinated compounds being used where performance requirements are less stringent. Brominated compounds are used in all major classes of plastics, chlorinated compounds are used in polyolefins, polyesters, and other general engineering resins, and halogenated phosphates are used in polyurethanes and engineering resins. Products containing these flame retardants are used throughout the building and construction industries, in transportation, in home furnishings and appliances, in textiles, and in electrical and electronic equipment.

Concerns over the possible adverse effects of the combustion of plastics-containing halogenated flame retardants have led to suggestions that they be banned. These suggestions have not been implemented because of uncertainty as to the factual bases for the concerns and because effective substitutes have not been found. (2) However, the major manufacturers of flame-retardant materials have been seeking to develop halogen-free compounds that would provide performance comparable to those based on chlorine and bromine. (3) Some new compounds, which are usually chemical variants of existing nonhalogenated compounds, have been marketed, but they have not gained significant market share as yet, probably because of their generally higher cost and performance limitations. For purposes of this analysis, however, we assume that suitable compounds exist or will be developed at some cost. We also assume that the substitutes will be modifications of the organophosphorus compounds available now, and probably will be of the class of complex phosphate esters. (4) Some compounds in this class are currently made using chlorine-containing intermediates, so the acceptable substitutes will include only those that do not involve chlorine chemistry. New capital investments will be required to produce these materials, and their costs will equal or exceed the costs of available phosphorus-based compounds. We also assume, conservatively, that synergists will be used and that they will be substituted for halogenated compounds on an equal weight basis. Our estimates of the total costs of substitution are summarized in Exhibit 3-12.

Exhibit 3-12. Benefits of Chlorine in Flame Retardants (U.S. and Canada)

Estimated 1990 flame retardant consumption (000 tons)	93
Substitutes	Organophosphorus compounds plus synergists
Estimated investment required ($Million)	260
Estimated incremental cost of substitutes ($Million/Year)	128
Estimated total cost of substitution ($Million/Year)	180

SOURCE: Charles River Associates, 1993.

In recent years the continued concern for the safety of consumer products has led to increased use of flame retardants in all market sectors, both on a voluntary basis and under the pressure of regulatory activities. We expect this trend to continue, providing flame-retardant manufacturers with market incentives to develop better, more cost-effective materials. In spite of a decade of increased R&D activities in this area, cost-effective substitutes for the halogenated compounds now in use have not been found. A ban on chlorine production could force consumers to make a choice between less fire resistant or more costly products.

References

(1) "Flame Retardants: No Burnout Yet," D. Caney, *Chemical Marketing Reporter*, April 27, 1992.

(2) "Flame Retardants: Regulatory Threat Promotes Halogen-free Formulations," *Modern Plastics*, September 1992, p. 63.

(3) "Flame Retardants: New and Tougher Standards Drive the Market," G. Morris, *Chemical Week*, April 15, 1992, p. 26.

(4) *International Plastics Flammability Handbook*, J. Troitysch ed., Macmillan Publishing Co., Chap. 5.

Chlorinated Polyolefins

Chlorinated polyolefins are a class of compounds manufactured by chlorinating olefin-based polymers such as polyethylene. This class also includes compounds that are sulfonated and based on copolymers of ethylene and vinyl acetate. (1) These materials have excellent physical and chemical properties, including toughness and resistance to weather, many corrosive chemicals, oils, and heat. They are used in a variety of industrial applications such as hoses and belts, gaskets and seals, tank liners and membranes, and electrical and cable insulation. They are also used for automotive applications such as spark plug boots and ignition wires, and for construction and consumer applications such as roof membranes, weather stripping, coated fabrics, and footwear. (2) Their properties are similar in many respects to those of polychloroprene, and they compete with that material in some applications.

As was the case with polychloroprenes, we can identify no readily available substitutes that have comparable properties, and some utility loss would occur if they were used. In less demanding applications, we believe that lower-cost high-density polyethylene or thermoplastic olefins might be substituted, but with replacement ratios over product lives that would range from two to five times higher. In the more demanding applications, the likely substitutes would be olefinic thermoplastic vulcanates or copolyester resins. Replacement ratios would be lower for these more expensive materials, but new manufacturing capacity would be required. The estimated net costs of substitution for chlorinated polyolefins are summarized below.

Exhibit 3-13. Benefits of Chlorine Chemistry in Chlorinated Polyolefins (U.S. and Canada)

Estimated 1990 consumption (000 tons)	85
Substitutes	High-density polyethylene, thermoplastic olefins, olefinic thermoplastic vulcanates, or copolyester resins, depending on the application
Estimated investment required ($Million)	170
Estimated incremental cost of substitutes ($Million/Year)	86
Estimated total cost of substitution ($Million/Year)	120

SOURCE: Charles River Associates, 1993.

We estimate that the net costs of substitution for chlorinated polyolefin products will be lower than for polychloroprene products because less costly substitutes can be used even though they would have shorter lives and would not provide the performance consumers have come to expect. These estimates do not contain allowances for the increased maintenance cost associated with using lower-performance substitutes, nor do they account for the economic penalties consumers would have to pay because of the products' reduced service lives. If the higher-performance substitutes were required in all applications, the net costs of substitution for these products would increase by at least $50 million per year.

References

(1) *1991 Rubber Red Book*, 43rd Ed., Communications Channels Inc., Synthetic Rubber.

(2) *Du Pont Hypalon® Synthetic Rubber: An Application Album*, Du Pont Company Elastomers Division, Publication E-43445.

Polyvinylidine Chloride

Polyvinylidine chloride products (PVDC) are copolymers of vinyl chloride monomer and vinylidine chloride, both of which are derived from ethylen dichloride, the starting material for PVC production. (1) Consumers are perhaps most familiar with the polyvinylidine chloride packaging products sold under the Saran® trade name.

These products are usually fabricated into films that are used in a variety of packaging applications or as protective films in medical applications. Some are used as adhesives and as laminates in rigid products, or as protective coatings on metals, woods, and papers. In many applications polyvinylidine chloride is used together with other polymer films to produce multilayer barriers with enhanced properties.

Film products made from polyvinylidine chloride are tear-resistant, have very low moisture and air permeation rates, have controllable shrinkage and vacuum packing characteristics, are transparent, and have self-adhesion properties that make them uniquely suited for packaging food products. (2) They have captured more than 80 percent of the market in food packaging applications because consumers value the ability to inspect packaged food prior to purchase, to store it until use without spoilage or degradation of appearance, and to repack and store foodstuffs in the home.

Other plastic and nonplastic materials such as waxed papers or metal foils can be used in packaging foods. However, the most likely substitutes that consumers would require to replace PVDC would be transparent films made from polymers of ethyl vinyl alcohol or linear low-density polyethylene. (3) These materials are not as effective as moisture and air transmission barriers, however, and thicker films would be required to preserve freshness. These substitutes do not have as favorable shrinkage and wrapping characteristics, either, so that spoilage losses and reduced shelf life are likely. We believe that films based on ethyl vinyl alcohol copolymers would capture most of the food packaging market, and that new manufacturing capacity would be required to produce it. We also believe that polyethylene-based films could compete more effectively based on price in nonfood packaging. Our estimates of the net cost of substitution for PVDC are summarized in Exhibit 3-14.

Exhibit 3-14. Benefits of Chlorine Chemistry in Polyvinylidine Chloride Products (U.S. and Canada)

Estimated 1990 consumption (000 tons)	56
Substitutes	Products based on ethyl vinyl alcohol copolymers and linear low-density polyethylene
Estimated investment required ($Million)	470
Estimated incremental costs of substitutes ($Million/Year)	86
Estimated total cost of substitution ($Million/Year)	180

SOURCE: Charles River Associates, 1993.

Consumers are most familiar with such PVDC uses as food packaging, but these materials are also used for packaging pharmaceuticals, cosmetics, and other products whose life or properties would be sensitive to degradation caused by infiltration of moisture, oxygen, or odors. Using substitute materials would not only be more costly to consumers, but would result in some deterioration in the properties of the materials packaged. In some cases, the degradation may be mainly cosmetic, as with the discoloration of packaged meats. In the case of pharmaceuticals, the degradation could decrease product effectiveness, and some other more costly form of packaging would be required.

References

(1) "Vinylidene Chloride (PVDC)," D. Clarke, *Modern Plastics Mid-October Encyclopedia Issue*, 1991. McGraw-Hill, p. 138.
(2) "Even George Bush Might Like This," J. Callari, *Plastics World*, June 1990, p. 53.

(3) "Dow's PVDC Investment Reflect Further Growth," D. Peterkofsky, *Chemical Marketing Reporter*, September 30, 1991.

Summary of the Benefits of Chlorine Chemistry in Chlorine-Containing Products

We estimate that the net benefits to consumers arising from the use of the chlorine-containing products evaluated here amounts to $34.7 billion per year, and that new investments of $12.2 billion would be required to produce substitutes for them. These estimates are conservative, since we have not estimated the benefits of many other chlorine-containing materials produced in smaller volumes, nor included the benefits that arise from the use of crop protection chemicals non-agricultural applications.

The amount of benefits these products provide is *not* related to the amount of chlorine they contain or the amount used in their manufacture. The benefits arise from their properties and the uses to which they are put. This characteristic becomes even more apparent as we examine the benefits of chlorine in applications where it does not appear in the final product at all.

Chlorine as a Facilitator

Propylene Oxide

Propylene oxide is a basic chemical building block. Its major use is as a component of the polyurethane resins used to make the flexible foamed material for household furnishings, carpets, insulation, and a wide variety of industrial products. It is also the raw material for the manufacture of propylene glycol, which is converted into polyester resin-based products such as recreational equipment, luggage, furniture and appliance parts, and building components. Propylene oxide is also the starting material for a host of other products such as the emulsifiers used in food products, the surfactants used in detergents, and the performance-enhancing additives in paints, adhesives, and hydraulic fluids. (1)

Propylene oxide is currently manufactured in two completely different ways: one manufacturing process is based on a propylene chlorohydrin intermediate; the other is based on the peroxidation of either isobutane or ethylbenzene. (2) Both of these processes are currently being used and are commercially viable, so a chlorine-free process can be substituted for the one based on chlorohydrin. The only issue is the cost of substitution, which depends strongly on capital requirements, feedstock availability, the price of raw materials, and byproduct credits.

The chlorohydrin-based process uses propylene as a feedstock. Propylene oxide is produced via a hypochlorination reaction. The chlorine is removed from the intermediate product by reaction with sodium hydroxide. When propylene oxide production is integrated with chlor-alkali production, the net result is simply the conversion of propylene to propylene oxide with the chlorine and sodium hydroxide streams reconverted to sodium chloride.

Starting materials for the peroxidation process are, in addition to propylene, either butane or ethylbenzene, which are products of oil refining. These hydrocarbons are selectively oxidized to produce hydroperoxides which are, in turn, reacted with propylene to produce the propylene oxide. The byproducts of these reactions are either tertiary butyl alcohol (from isobutane) or alpha methyl benzyl alcohol (from ethyl benzene). These byproducts are building blocks for the formation of other chemicals: tertiary butanol can be converted to methyl tertiary butyl ether (MTBE), which is used to promote complete combustion of gasoline, and the methyl benzyl alcohol can be converted to styrene, the starting material for polystyrene-based plastics. (3) A producer contemplating entering the propylene oxide market by using one of these processes would base the decision largely on the cost and availability of isobutane and ethylbenzene and the markets for the byproducts. In practice, such a decision would be made on strategic grounds given the company's position in raw materials and downstream products as well as future business objectives. (4)

Since both peroxidation processes are in use, they must have comparable economics, and we have made no attempt to distinguish between them. Assuming reasonable long-term prices for the starting materials and credits for the byproducts, we estimate that the *net* cash costs of production by the peroxidation processes are slightly lower than those of the older chlorohydrin-based process. While the conversion costs of the chlorohydrin process are estimated to be lower than for the peroxidation routes, the byproduct credits available to the peroxidation processes are more than sufficient to offset the extra raw materials costs and the higher conversion costs of the more complex processes. We estimate that approximately 45 percent of current domestic consumption is based on the chlorohydrin route, and our estimates of the costs of substitution by a peroxidation process are summarized in Exhibit 3-15.

Exhibit 3-15. Benefits of Chlorine in Propylene Oxide Production (U.S. and Canada)

Estimated 1990 consumption (000 tons)	535
Substitute process	Peroxidation of either isobutane or ethylbenzene
Estimated investment required ($Million)	1,060
Estimated incremental manufacturing costs ($Million/Year)	(22)
Estimated total cost of substitution ($Million/Year)	190

SOURCE: Charles River Associates, 1993.

Our estimates showing that the net cash costs of production are lower for the peroxidation routes than for the chlorohydrin route are very sensitive to the relative costs and credits of the feedstocks and byproducts. Future changes in the markets for either would change the economic impact estimated here. Apart from these economic factors, some consideration would have to be given to the relative health, safety, and environmental consequences of operating plants based on these processes. Selective oxidation of hydrocarbons, while practiced for many years, must be controlled very carefully to minimize the risks of highly energetic and destructive runaway reactions. (3)

References

(1) "Chemical Profile — Propylene Oxide," *Chemical Marketing Reporter*, July 1, 1990.
(2) *Riegel's Handbook of Industrial Chemistry*, 9th Ed., J. Kent ed., Van Nostrand Reinholdt, p. 831.
(3) "Propylene Oxide Producers Look for Ways to Counter Sluggish Market," S. Answorth, *Chemical and Engineering News*, March 2, 1992, p. 9.
(4) "Texaco Chemical to Build Propylene Oxide/MTBE Plant," *Chemical Marketing Reporter*, June 24, 1991, p. 3.

Isocyanates

Toluene diisocyanate (TDI), methylene diisocyanate (MDI), and other isocyanates are the basic building blocks which, when reacted with polyols derived largely from propylene oxide, form polyurethane resins. Resin properties can be varied to produce products ranging from the flexible foams used in furniture and bedding to rigid products used in industrial applications to protective coatings used on flooring and other surfaces by changing the isocyanates and polyols used. (1) In general, TDI is used in the production of flexible foams, MDI in the production of rigid foams, and a variety of other aliphatic and polymeric isocyanates are used in a variety of specialty applications and in coatings. (2)

TDI, MDI, and other isocyanates are all made by reactions between phosgene and an appropriate amine. Phosgene, which is highly toxic, is made on-site by reacting chlorine and carbon monoxide. (3) Toluene diamine, made by hydrogen reduction of dinitrotoluene, is the other starting material for TDI producti n. Methylene diphenyl diamine, made by condensing analine with formaldehyde, is the other starting material for MDI. (4)

Phosgene production is a simple, single-step process, and synthesis of the isocyanates usually proceeds in two steps through chloride-containing intermediates. The separation and purification of the products of reaction from the polymeric byproducts that are formed is a multistep process, but is straightforward. Even though this technology has been the basis of commercial isocyanate production for many years, the patent literature contains numerous examples of process routes that do not involve phosgene. (5) Most of the processes described involve either the direct catalytic carboxylation of reactants or the formation of intermediates that are subsequently converted by a series of reaction-separation steps to form isocyanates.

In general, the carboxylation processes may be carried out under either oxidizing or reducing conditions. Aniline may be reacted with carbon monoxide, oxygen, and an alcohol over a precious metal catalyst at high pressure to form a dicarbonate, for example. The dicarbonate would then be decomposed thermally to regenerate the alcohol for recycling and to produce MDI. Dinitrotoluene may be reacted with carbon monoxide and an alcohol over a precious metal catalyst in the absence of oxygen to produce a dicarbonate. This dicarbonate would be decomposed to regenerate the alcohol and produce TDI. An alternate approach would be to react carbon dioxide and ammonia to produce urea, and then synthesize a carbonate by reaction between urea and an amine. (6) Any of these approaches involve as many reaction and separation steps as current phosgene-based technology and some would operate at more severe conditions, so that it is unlikely that investment requirements could be significantly lowered. Also, the use of precious metal catalysts and the relatively low yields that are reported in the patent literature would lead to operating costs that are higher than can be achieved using phosgene, so it is not surprising that none have been commercialized.

One producer, Daicel Chemical of Japan, has announced the construction of a semiworks scale plant for production of the specialty isocyanate, IDPI, by direct reaction between dimethyl carbonate (DMC) and diamines. The dicarbonate intermediate is pyrolized to form the isocyanate, no precious metal catalysts are required, and no chlorine chemistry is involved. DMC production is a complex, multistep process, however, as is the subsequent process for reacting DMC with its amine and the separation and purification of the reaction products. While reaction conditions are relatively mild, this type of a two-step process would be capital and energy intensive because of the complex series of separation steps required.

There is sufficient information in the literature to indicate that some versions of catalytic carboxylation technology would provide technically feasible chlorine-free routes for isocyanate production. Based on schematic descriptions of a "typical" process sequence and estimates of likely process conditions and achievable conversion and yields, we estimate the costs of substitution as shown in Exhibit 3-16.

Exhibit 3-16. Benefits of Chlorine in Isocyanate Production (U.S. and Canada)

Estimated 1990 consumption (000 tons)	745
Substitute process	Catalytic carboxylation
Estimated investment required ($Million)	1,130
Estimated incremental manufacturing costs ($Million/Year)	154
Estimated total cost of substitution ($Million/Year)	380

SOURCE: Charles River Associates, 1993.

Adopting this technology would eliminate the risks associated with the production and use of phosgene and the generation of some chlorine-containing byproducts. However, its use would create new risks associated with the handling of toxic and flammable carbon monoxide at high pressures. Furthermore, it would be highly energy intensive, both in the separation steps required in the process and in the manufacture of the natural gas-based carbon monoxide, which is used at much higher efficiency in phosgene-based processes.

References

(1) *Handbook of Thermoset Plastics*, S. Goodman ed., Noyes Publications, 1986, Chap. 7.

(2) "Tougher Times Ahead for Polyurethane," D. Jackson and L. Tattum, *Chemical Week*, October 9, 1991, p. 32.

(3) *Kirk–Othmer Encyclopedia of Chemical Technology*, 2nd Ed., J. Wiley & Sons 1963, Supplemental Volume.

(4) Ibid., Vol. 23.

(5) *Process for the Preparation of Methylene Diphenylene Diisocyanates and Polyethylene Polyphenylene Diisocyanates*, U.S. 4,873,364, E. Shawl and H. Kealing to Arco Technology, Inc.

(6) "A Non-phosgene Route for the Synthesis of Alkyl N-Phenylcarbonate," U. Kalkote and N. Ayyangar, *Chemistry and Industry*, June 17, 1991, p. 435.

Epichlorohydrin Products

Epichlorohydrin is used as one of the key raw materials for producing a wide variety of resins. The starting materials for most epoxy resins are made by reacting epichlorohydrin with the phenolic compound bisphenol A to form chlorinated diethers. The diethers are then treated to remove the chlorine (which is converted back to sodium chloride) to form diglycidyl ethers. Resins with a wide range of properties can be produced by varying reaction and curing conditions, modifying the resins by reacting them further with other materials or diluents, or substituting other starting materials such as cycloalipatic carboxylic acids for the phenolic component of the compound. (1) Resins with an epoxy structure can be produced by reacting peroxides with unsaturated compounds such as fatty acid esters or aliphatic olefins, but these materials have very different properties from resins based on epichlorohydrin. Epichlorohydrin-based resins can be formulated with properties that range from low-molecular-weight viscous liquids to high-molecular-weight thermoplastics.

The ability to produce resins with tailored properties has led to the use of epoxy resins in a wide variety of applications. About half of the epichlorohydrin-based resins produced are used as coatings, mainly in beverage cans and to protect the surfaces of appliances and equipment from corrosive environments. Two component systems, with a curing agent in one container and the resin in the other, are sold for household use as adhesives. Epoxies modified with fatty acids are the basis for air-dried floor coatings. Epoxy resins are applied to reinforcing materials, mainly glass fibers, and cured to form fibre-reinforced laminates. These types of products have a number of important industrial applications. They are used almost universally as the substrates for printed circuit boards and are the bases of high-performance composite materials for aerospace uses. Other types of resins are used in adhesives and electrical components and are fabricated into a variety of engineering products. (2,3)

Epichlorohydrin is also used to manufacture other materials, including polyamines, wet-strength resins, and elastomers with tailored properties. These materials are used as coagulating agents in water treatment, to improve the strength of paper products, and for a variety of industrial uses. Chlorine-free chemistries have not been developed that can produce these materials, or epoxy resins, with the desired properties. Therefore, any substitution required by a chlorine production ban would occur at the derivative product level.

The most likely substitutes for epoxy products in protective coatings would be based on polyurethanes or phenolics, although substitution ratios would exceed unity for the phenolics because their properties are not as good as epoxies. Unsaturated polyester resins and, for more demanding applications, polycyanate-based resins, are the most likely substitutes for epoxy resins in printed circuit boards and other reinforced laminate structures. (4) Polyurethanes and unsaturated polyester-based materials are assumed to be major substitutes for miscellaneous other applications of epoxy materials, but the uses are highly fragmented. Polyacrylaurides and urea formaldehyde resins are the most likely substitutes f r epichlorohydrin-based polyamines and wet-strength resins, while a variety of performance elastomers, including nitrile butadiene rubbers, nitrile thermoplastic elastomers, and olefinic thermoplastic vulcanates, are assumed to be the most likely substitutes for specialty epichlorohydrin-based elastomers. The estimated costs of substitution for these types of products are summarized in Exhibit 3-17.

Exhibit 3-17. Benefits of Chlorine in Epichlorohydrin Products (U.S. and Canada)

Product Type	Epoxy Resins	Other Products
Estimated 1990 consumption (000 tons)	208	50
Substitutes	Various resins and elastomers, depending on applications	
Estimated investment required ($Million)	120	0
Estimated incremental cost of substitutes ($Million/Year)	381	75
Estimated total cost of substitution ($Million/Year)	405	75

SOURCE: Charles River Associates, 1993.

As is the case with other specialty materials described earlier in this chapter, available substitutes may not be able to provide equivalent performance, even if they are higher in price. For example, bromine-modified epoxy resins are used widely as substrates for printed circuit boards because they are flame resistant and therefore serviceable at higher temperatures than unmodified resins. It is not clear that substitute materials incorporating the chlorine- or bromine-free fire retardants described earlier can achieve the same rating. If not, manufacturers of devices using closely stacked PC boards will have to modify their designs or reduce their efficiency, which would entail cost penalties not estimated here.

References

(1) *Engineered Materials Handbook, Vol. 2 — Engineering Plastics*, SM International, 1988, p. 240.

(2) *Epoxy Resins Chemistry and Technology*, 2nd Ed., C. May ed., Marcel Dekker, Inc.

(3) "Epoxy," J. Gannon, *Modern Plastics Mid-October Encyclopedia Issue*, 1991, Mcgraw Hill, p. 140.

(4) *Engineered Materials Handbook, Vol. 2 — Engineering Plastics*, SM International, 1988, p. 232.

Titanium Dioxide

Titanium dioxide is produced from titanium-containing ores or slags, and is an important pigment used to impart both whiteness and opacity. Its high refractive index, chemical inertness, and low toxicity have led to its use in applications formerly held by lead- and zinc-based pigments. It is used in paints and coatings to provide color and hiding power and to improve resistance to washing and weather. It is used in paper and plastics to improve whiteness and opacity, and in a variety of other products including ceramics, tires, cosmetics, and pharmaceuticals. (1) Two major process routes are in use worldwide for titanium dioxide production: one based on chlorine and the other based on sulfuric acid.

The major raw materials used for titanium dioxide production are natural or synthetic rutile ores that are high in titania, ilmenite ores that contain higher amounts of iron oxides, and titania rich slags that are produced as byproducts of electric furnace iron production. Both the chloride- and sulfate-based processes have been used on all of these materials, but the choice of process route may rest on the disposal options available for the iron contained in the feed material. While high titania slags are produced in Canada, the low-cost ilmenite ores available in the United States have higher iron contents. The available high-titania, low-iron rutile ores are imported and are much more expensive. The iron and other impurities are separated chemically from the titania within the processes, and are disposed of as either chloride or sulfate salts, depending on the process. (2)

In some plants of each type, the waste iron salts have been disposed of with minimal additional treatment by landfill, deep-well injection, discharge to waterways, or ocean dumping. In some cases, the iron-bearing wastes have been purified, upgraded, and sold as flocculating agents to water treatment plants. The lower costs of treating or upgrading iron chlorides is a major reason for the widespread use of the chlorine-based process in the United States. Eighty percent of U.S. and Canadian production is currently based on the chloride process, and this capacity would have to be replaced by sulfate-based processes if chlorine production were banned.

We assume for this analysis that new production of *any* substitute would have to meet current environmental regulations. In some locations, landfilling of neutralized, stabilized sulfate wastes might be permitted, although the cost would be high. In other locations, producers would probably elect to install acid recovery operations to reduce the amount of material to be discharged. These operations are capital and energy intensive, and increase the conversion costs for the process significantly. The only other way to reduce these costs is to secure raw materials that are higher in titania, but this will bid up their prices on the international markets and increase product costs as well. Based on our evaluation of the relative costs of titanium-containing raw materials, processing costs, and the costs of meeting current environmental regulations, we estimate the costs of substituting sulfate for chloride-based technology as shown in Exhibit 3-18.

Exhibit 3-18. Benefits of Chlorine in Titanium Dioxide Production (U.S. and Canada)

Estimated 1990 production (000 tons)	740
Substitute process	Sulfuric acid treatment of ilmenite
Estimated investment required ($Million)	1,850
Estimated incremental manufacturing costs ($Million/Year)	110
Estimated total cost of substitution ($Million/Year)	480

SOURCE: Charles River Associates, 1993.

The capital requirements for a sulfate-based product that would meet current requirements for waste disposal are significantly higher than for older plants. Recent environmental control projects at older plants have been reported to require about $1,000 per annual ton of production. (3) The consequence of not making these investments, however, is the creation of significant environmental problems that the current chlorine-based technology avoids.

References

(1) *Chemical Process Industries*, 5th Ed., R. Shreve and J. Brink eds., McGraw–Hill, p. 433.

(2) *Kirk–Othmer Encyclopedia of Chemical Technology*, 2nd Ed., J. Wiley & Sons, 1963, Vol. 20.

(3) Tioxide Advances TiO_2 Technology, D. *O'Sulivan Chemical and Engineering News*, June 10, 1991, p. 33.

Pharmaceutical and Healthcare Products

Products in this category include prescription and over-the-counter drugs, healthcare products such as test kits and opthomalic solutions, and sundries such as vitamin supplements and dieting aids. As a class, these products constitute a major element of the healthcare system that also includes the services provided by hospitals, physicians, nursing homes, and others. Because of the importance of chlorine chemistry in the manufacture of these products and because of the magnitude of the benefits they provide, the methodology we have used to estimate the benefits is described in some detail.

We are seeking in this analysis to determine the healthcare-related costs to consumers of a ban on chlorine use in the manufacture of pharmaceuticals and other healthcare products. The immediate costs of banning chlorine used for disinfecting water and of banning hypochlorites used as surface disinfectants in food processing and in hospitals, and so on, have already been estimated. We assume for this analysis that the substitutes used would be just as effective as the chlorine-based products that would be banned, and that no *new* health-related c sts would be incurred from their substitution. We also assume that the banning of chlorine chemistry in all other uses would not result in a *net* change in the costs of healthcare either. This assumption regarding no net change in healthcare costs can be tested with further research that is beyond the scope of this project. Some health costs are likely to decline by banning chlorine-dependent products because the health risks associated with worker exposure and other health-related problems attributable to specific compounds would be eliminated. Analogous reductions could be expected in the population of employees involved in the use of chlorinated compounds in downstream operations and elsewhere. We expect such reductions to be small, however, since most uses of chlorine are not distributive and the great majority of chlorine-based products encountered by consumers are non-toxic and do not even contain chlorine.

On the other hand, the manufacture of the substitutes that would have to be used if chlorine production were banned would have their own environmental or health-related impacts. The coal mining and coke production required to produce the ductile iron to displace PVC pipe in certain applications, for example, would entail employee exposure to conditions and compounds that would lead to increased healthcare costs for those sectors. Using flammable solvents to displace chlorinated ones in dry cleaning and in manufacturing operations would inevitably lead to more fire-related healthcare costs. These compounds have also been implicated in the formation of photochemical smogs, which create health risks, and hydrocarbon-based materials are toxic, so that some increased healthcare costs would be expected from incidental exposure to them. *In effect, we assume that the decreases in healthcare costs that could be attributed to a chlorine production ban would be offset by the increases in costs that would be attributed to the production and use of substitute materials.*

The costs of pharmaceuticals and other healthcare products are only one component of total healthcare costs. Data available for the distribution of healthcare costs in the United States in 1990 and the estimated distribution for Canada are summarized in Exhibit 3-19.

Exhibit 3-19. Estimated 1990 Healthcare Cost Distribution in the United States and Canada

	Cost ($Billion)		
	U.S.	Canada[1]	Total
Pharmaceuticals and sundry products	54.6	6.7	61.3
In-patient care	256.0	19.5	275.5
Physicians and other costs	332.8	20.1	352.9
Total costs	643.4	46.3	689.7

Note:
(1) Cost in U.S. dollars.

SOURCE: Charles River Associates, 1993, from *Health Care Financing Review*, HCFA, Winter 1990.

In 1987, total Canadian expenditures amounted to 7.2 percent of those in the United States, less than would be expected based on a population ratio basis. The fraction of the total attributable to pharmaceuticals was higher in Canada, however, at 11.6 percent, suggesting that they may be a cost-effective agent in the management of the healthcare system there. No data were available for the distribution of Canadian costs in 1990, but assuming that the relative distributions of costs had not changed leads to our estimate of total healthcare costs in the United States and Canada in 1990 of $689.7 billion, with a total expenditure for pharmaceuticals of $61.3 billion, about 8.9 percent of the total.

If the use of pharmaceuticals based on chlorine chemistry were not possible, the following actions might be taken:

- Consumers could accept the loss of the products without seeking substitutes and simply accept the decreases in their healthcare status without further action.

- Physicians could prescribe the best substitute from among the pharmaceuticals remaining, and consumers could select from the remaining nonprescription products, accepting the resulting changes in their health status without further action.

- Having selected the best possible chlorine-free substitute, consumers could seek to use the remaining components of the healthcare system — hospitals, physicians, nursing care facilities, home healthcare providers, and so on — to restore their healthcare status to the previous level of quality.

For this analysis, we assume consumers would select the third option. That is, we do not believe consumers would accept decreases in the quality of their healthcare because a ban on chlorine-dependent products had restricted their choices of pharmaceuticals and other products. They would substitute other services as well as other pharmaceuticals to satisfy their healthcare needs, and this would result in cost increases in these services as consumers bid for their use. Costs for pharmaceutical purchases might decrease if the remaining chlorine-free compounds happened to be less expensive and were not used at higher doses or rates as a consequence of this substitution. The extent of the *net* change in the cost to consumers, as the use of the other components of the healthcare system is increased to offset the loss of chlorine-based drugs, can be estimated using the Cobb–Douglas model described in Appendix A.

To use the Cobb–Douglas model in this case, we must determine the extent to which a ban on chlorine use would affect the availability of pharmaceuticals and other healthcare products. The 206 largest-selling pharmaceuticals and healthcare products in the United States in 1990 were taken as a representative sample of all products in this class. (2) Information on their composition and methods of manufacture was obtained from the patent literature and other published sources. (3,4,5) The products were sorted into therapeutic groups (6), and were characterized on the basis of their involvement with chlorine chemistry as:

- Compounds that were sold as the therapeutically active hydrochloride salt.

- Compounds that contained chlorine or bromine bound covalently to the structure.

- Compounds that were synthesized using chlorine-containing intermediates or that used chlorinated solvents or other chlorine-based materials in the manufacturing process.

- Compounds that did not involve chlorine chemistry in their manufacture.

Many patents contained numerous examples of different compounds or synthesis methods that were within the scope of the claims, some of which were based on chlorine and some of which were not. A drug was considered to be based on chlorine chemistry only if more than 90 percent of the examples cited were chlorine-based. The results of the survey of pharmaceutical production technology are summarized in Exhibit 3-20.

Sales of the sampled products totaled more than $25 billion, or more than 40 percent of the estimated total sales in the United States and Canada in 1990. No product excluded from this sample had sales that exceeded $36 million. The sample size of the biologicals group was only four products, with total sales of $205 million. The products in this group include blood products and vaccines, and the lack of involvement of chlorine chemistry in their manufacture is not surprising. Seven products were sampled in the blood modifier group, and three, with sales of $423 million, did not involve chlorine chemistry. They included two new and costly products manufactured by genetic engineering techniques and a natural product derived from animal sera. The remaining therapeutic groups had from 62 to 98 percent of their sales value from products based on chlorine chemistry. For the entire sample of 206 products, 85 percent of the number of products were based on chlorine chemistry, which represented 84.5 percent of the total sales volume.

Estimating the Economic Benefits of Chlorine

Exhibit 3-20. Use of Chlorine Chemistry in the Manufacture of Pharmaceuticals and Other Healthcare Products

Therapeutic Group	Number of Products Surveyed	Percent of Sales in the Group With			
		Hydrochloride in Product	Chlorine on Molecule	Chlorine in Manufacture	No Chlorine
Nutritionals	8	0	0	92.2	7.8
Blood modifiers	7	0	0	46.1	53.9
Hormones	20	0	11.9	70.7	17.4
Cardiovasculars	43	2.4	28.6	46.6	22.4
Respiratory drugs	16	4.7	24.5	49.6	21.2
Central nervous system drugs	39	16.0	31.7	44.0	8.3
Gastrointestinals	9	0	0	97.9	2.1
Anti-infectives	36	8.4	14.5	69.9	7.2
Biologicals	4	0	0	0	100.0
Topical preparations	12	15.7	26.8	52.2	5.3
Antineoplastics	6	0	27.8	34.5	37.7
Miscellaneous	6	0	0	80.3	19.7
Total all groups	206	6.1	20.3	58.1	15.5

SOURCE: Charles River Associates, 1993.

In some groups, gastrointestinals for example, a ban on chlorine production is tantamount to a ban on the production of that group or class of therapeutic agents. More than 90 percent of the compounds in the nutritionals, central nervous system drugs, gastrointestinals, anti-infectives, and topical preparations would no longer be available. These represent about half of the total sales sampled, and it would be extremely difficult, if not impossible, to substitute the remaining products to obtain clinically similar results within the groups. Very few synthetic antibiotics would be available, for example, so that less-effective compounds would have to be used in the treatment of bacterial infections. This would increase the demands on the other components of the healthcare system because longer hospital stays or more frequent attendance by a physician would be required. If we assume that only 15.5 percent of all currently used compounds would be available as a result of a ban on chlorine production, the Cobb–Douglas model predicts that the *net* costs to consumers would be $73.6 billion per year. This is a very significant cost, but is only 42 percent more than the costs of the products affected by a chlorine ban.

It is highly likely, however, that the pharmaceutical industry would react to a ban on chlorine use by developing new products in an attempt to retain its share of total healthcare expenditures. An obvious response would be to seek to replace the products currently sold as hydrochlorides with products based on the salts of other acids such as hydrofluoric, nitric, phosphoric, citric, and so on. The rationale for this is that process changes would be minimized, and it *might* be possible to conduct the necessary clinical trials for a new chemical entity on an accelerated basis. *Assuming* that such compounds are found to be therapeutically equivalent, they could probably be produced with modest increases in prices, perhaps on the order of five percent above current (1990) levels for these products. If this were possible, the fraction of compounds depending on chlorine chemistry would drop to about 78 percent of the total, and the Cobb–Douglas model would predict a net cost increase of $53.6 billion per year. This is about 12 percent more than the sales value of the products that would be affected.

A ban on chlorine use would eliminate the 20.3 percent of products that contain chlorine on the molecule, and it is unlikely that therapeutically equivalent results could be obtained by substituting, for instance, fluorine or some other functional group for chlorine. Attempting to demonstrate equivalence would, in all likelihood, require a long and costly research and clinical demonstration effort. It is possible, however, that alternate chlorine-free manufacturing procedures could be found for some of the products that now depend on chlorine. While additional research and process development costs would be incurred, regulatory costs would be minimized if it could be shown that a clinically equivalent product was produced. The obvious targets would be those processes that used chlorinated solvents for separation or purification steps, or used hydrochloric acid or caustic for pH adjustment under circumstances where other acids or bases could be substituted with manageable impacts on the process chemistry. These situations represent about 20 percent of those in which chlorine is used in manufacturing, or about 11 percent of all compounds.

The new manufacturing processes would be significantly more costly than the existing ones, however. We estimate that price increases might range from 5 to 20 percent depending on the increase in process complexity. Also, significant investments would be required in new production equipment, although it is likely that use of existing facilities could be largely retained for the new processes. A rough estimate of new investment requirements places them on the order of $0.2 to $0.5 billion, and if we assume that prices for these products would increase by only 10 percent, the Cobb–Douglas model predicts that *net* costs to the consumer would increase by $31.9 billion per year. That is, sales of the remaining chlorine-based products of some $40.9 billion per year would be foregone, but the costs of the remaining components of the healthcare system would increase by some $72.8 billion per year. We believe that this is probably a lower bound on costs, since it is by no means clear that such process substitutions could be achieved *at the assumed prices*. The results of this series of assumptions on the possible substitution for chlorine-based products are summarized in Exhibit 3-21.

Exhibit 3-21. Benefits of Chlorine in Pharmaceutical and Healthcare Products (U.S. and Canada)

Substitute	Estimated New R&D Investment(1) ($Million)	Estimated Incremental Costs of Healthcare ($Billion/Year)	Estimated Total Cost of Substitution ($Billion/Year)
Other medical services for all current chlorine-based compounds	–	73.5	73.5
Replace hydrochlorides and substitute other services for all other chlorine-based compounds	<50	53.6	53.6
Replace hydrochlorides plus new processes for 20% of current chlorine-based manufacture	<500	31.9	32.0

Note:

(1) Assumes no investments beyond current levels required in hospitals and other facilities to accommodate increased demands.

SOURCE: Charles River Associates, 1993.

In the last case evaluated, the *net* costs of substitution have been reduced to 78 percent of the costs of the products displaced. Obviously, if all chlorine-dependent products could be manufactured by alternate technologies with reasonable cost penalties, only the use of the 20.3 percent that contains chlorine would be foregone and the net costs to the consumers would be minimized. If all remaining chlorine-dependent drugs could be produced with increases in prices of only 50 percent, the net costs to consumers would be reduced to about $11 billion per year. Capital recovery charges on the new investment required, which would probably be on the order of $10 to $20 billion could increase net costs by an additional $2 to $4 billion per year. If, however, prices of the products manufactured without chlorine chemistry were doubled, net costs to consumers would increase to about $32 billion per year excluding capital recovery.

The therapeutic properties of pharmaceuticals depend on their structure as well as chemical composition and other factors such as dosage form. The structure of many pharmaceuticals is quite complex and is not achieved easily without the use of chlorine-containing intermediates. It is always possible to find alternate chemistries for producing a compound, but in the case of pharmaceutical chemicals, chlorine-free processes are apt to be complex and costs high because yields will be low. Genetic engineering techniques and advances in biotechnology offer the prospect for entirely new routes for producing new classes of pharmaceuticals, but it is by no means clear that these products would be less costly than the ones produced through chlorine chemistry or would provide the same therapeutic benefits.

It is not possible in a study of this scope to predict the cost, timing, or outcome of future research in this area, much less estimate new product costs with any degree of certainty. Application of the Cobb–Douglas model to this problem shows that the net benefits of chlorine chemistry to consumers in pharmaceuticals depends most strongly on two factors. They are the extent to which therapeutically equivalent chlorine-free products could be developed as substitutes for the chlorine-based products currently in use, and the extent to which the prices of the substitute products would exceed the prices of the products they displaced. We believe, however, that the estimates presented in Exhibit 3-21 define the likely *bounds* of the net costs to consumers of a ban on chlorine use; costs would be between $30 and $75 billion per year. For purposes of this analysis, we have taken the central value of $53.6 billion per year to be a technically feasible, mid-range estimate.

References

(1) *Health Care Financing Review*, U.S. Health Care Financing Administration, Winter 1990.
(2) *U.S. Pharmaceutical Market: Drug Store and Hospital Purchases, 1990.* IMS American Ltd., Pharmaceutical Database Division, 1991.
(3) *Pharmaceutical Manufacturing Encyclopedia*, 2nd Ed., Vol. 1 and 2, Marshall Sittig, Noyes Publications, 1988.
(4) *Physicians' Desk Reference*, 44th Ed., Medical Economics Co., 1990.
(5) *The Merck Index*, 11th Ed., Merck & Co., Inc., 1991.
(6) *Drug Facts and Comparisons*, J.B. Lippincot Co., Facts and Comparisons Division, Latest Supplements.

Refrigerants

Refrigerants are a class of compounds that are used as working fluids in mechanical refrigeration systems. They are the materials that absorb energy and provide cooling by evaporating at low temperatures and then releasing the energy by condensation at a higher temperature in another part of the refrigeration system. Refrigerants are selected for use in various systems based on their physical properties, their compatibility with the construction materials used, and their safety. A variety of compounds have been used as commercial and industrial refrigerants, including ammonia, low-molecular-weight hydrocarbons, and a class of compounds known to consumers by the brand name Freon®. (1) This class of materials, which is composed of a number of chlorinated and fluorinated compounds, was widely used in appliances and residential and automotive systems. The chlorofluorocarbon materials are generally compatible with the usual construction materials used in the systems, are nonflammable and nontoxic, and have the desired physical properties. Some of these compounds also have been used as cleaning solvents and as blowing agents in the manufacture of expanded plastic products, including the foamed material that serves as insulation for household refrigerators. In these applications, they may be released directly to the atmosphere.

Under normal use, refrigerants are contained within a sealed system. Such systems may be damaged or may leak slowly, however, and the refrigerants have to be removed to perform maintenance on the mechanical components. The refrigerants are relatively volatile and may escape to the atmosphere unless measures are taken to capture them. Unfortunately, some of the more widely used chlorofluorocarbon compounds have been found to have significant ozone depleting potential, and their release may cause environmental damage. The potential consequences of the damage have been judged to exceed any continued benefits from their use, and their production has been banned. Policymakers recognized that some time would be required to develop substitutes for the materials and systems currently in use, so a phase-out schedule for their replacement was developed and is being implemented. (2)

In general, it is not possible to simply substitute one refrigerant for another in a mechanical refrigeration system without imposing a severe performance penalty because of differences in the physical properties of the refrigerants. Thus, the ban on ozone-depleting chlorofluorocarbons will require that equipment designed to use them eventually be replaced with equipment designed to use other sanctioned refrigerants. These costs are not considered here because they result from policies that have already been put in place and do not require a ban on chlorine production. The designers of refrigeration systems must select *some* refrigerant, however, and current materials of choice for appliance, residential, automotive, and commercial systems appear to be compounds from the same class, such as HFC-134a, that do not have ozone-depleting potential. (3) Materials such as ammonia or propane, while used in industrial systems, are not favored in these applications because of the safety hazards associated with their accidental release. A number of more exotic refrigeration cycles based on other technologies or other working fluids have been proposed and some have been tested, but none have been shown to be commercially viable in the applications considered here. (4)

Refrigerants such as HFC-134a do not contain chlorine, but are synthesized from chlorine-containing precursors. As in the case with fluoropolymers, the most likely substitute for the currently used manufacturing process is one based on direct fluorination. There is no evidence in the literature indicating that such a process has been attempted, but there is no apparent reason why such a process would not be *technically* feasible. The most likely reason that this technology is currently not in use is that it is difficult to control the selectivity of such reactions, and yields could be low. This would increase manufacturing costs because of the increased costs for raw materials as well as separation and purification costs. Based on a scoping definition of the likely process configuration and costs, our estimates of the net costs of substituting direct fluorination for current processes for the manufacture of hydrofluorocarbon refrigerants are summarized in Exhibit 3-22.

Exhibit 3-22. Benefits of Chlorine in Refrigerant Manufacture (U.S. and Canada)

Estimated 1990 consumption (000 tons)	50
Substitute process	Direct fluorination
Estimated investment required ($Million)	250
Estimated incremental manufacturing costs ($Million/Year)	500
Estimated net cost of substitution ($Million/Year)	550

SOURCE: Charles River Associates, 1993.

In the chlorine-based manufacturing processes currently in use, the chlorinated precursors are instrumental in permitting fluorination reactions to be carried out selectively and with reasonable yields. Most of the chlorine in the precursors is converted to hydrogen chloride as a byproduct of the reactions, and the acid is sold or is neutralized and disposed. Nonselective fluorination would result in the creation of large amounts of fluorinated compounds. These materials could create environmental problems if released without proper treatment, and a significant fraction of the increased manufacturing costs estimated for the substitute technology are assigned to waste treatment.

The consumption estimates used here are for current use of HFCs that have no ozone-depleting potential. This is about one third of the recent consumption of refrigerants whose use has been or may be restricted. (5) If these HFCs or similar compounds based on chlorine chemistry are found to be the most efficient substitutes for the banned materials, their future consumption would be greater than estimated here. Net benefits to the consumer would then be greater than net benefits estimated based on current consumption.

References

(1) *Perry's Chemical Engineers' Handbook*, 6th Ed., R. Peng and D. Green, McGraw-Hill, 1990, Chap. 12.
(2) "Industry, Consumers Prepare for Compliance with Pending CFC Ban," P. Zurer, *Chemical and Engineering News*, June 22, 1992, p. 7.
(3) "Giving CFCs the Cold Shoulder," P. Knight, *Financial Times*, September 2, 1992.
(4) *Energy Efficient Alternatives to Chlorofluorocarbons*, Arthur D. Little, Inc., April 1992, Reference: 66384.
(5) "Chemical Profile — Fluorocarbons," *Chemical Marketing Reporter*, March 16, 1992.

Polycarbonate Products

Products made from polycarbonate resins are used in a variety of applications in the architectural and transportation sectors and in consumer products. Consumers are perhaps most familiar with the extremely tough, transparent sheets of polycarbonate, made under the trade name Lexan®, which are used in glazing applications. Their resistance to breakage provides a greater measure of personal safety than does glass. Clear polycarbonates transmit 96 to 98 percent as much light as glass with low distortion, are lower in weight, resistant to weathering, and insensitive to temperature change. These properties have led to their widespread substitution for glass in transportation and construction applications such as bus, train, subway car and aircraft windows, and windows on institutional buildings such as churches, stores, schools, and banks. Polycarbonates can also be used for larger components such as panels and domes in stadiums, with great savings in structural costs because of their low weight. (1)

In other applications, the high-impact strength and toughness of polycarbonates makes them extremely useful in the manufacture of parts for equipment and appliances. Examples include housings for computers and other electrical and electronic equipment, housings for large and small household appliances and tools ranging from vacuum cleaners to can openers to power drills, sports and recreation equipment such as protective helmets and face shields, low-weight energy-saving components for automobiles such as head and tail lamp housings, and low-weight containers such as those used to hold five gallons of bottled water. The information storage platform for compact audio disks is also fabricated from a polycarbonate resin. It is the material of choice for this application because of the mechanical properties described above and because it can be fabricated into a smooth, defect-free surface that can be used for reliable information storage. These characteristics arise from the chemical properties of the resin and its method of manufacture. (2)

Most polycarbonates are synthesized by the reactions between phosgene and bisphenol A. (The uses of bisphenol A and phosgene in the manufacture of epoxy resins and in the manufacture of isocyanates have been discussed in previous sections of the chapter.) The bisphenol A is dissolved to form an aqueous solution containing an excess of a base such as calcium or sodium hydroxide, and the solution is brought into contact with a water-immersible solvent such as methylene chloride. Phosgene is added to the liquids, and the polycarbonate that is formed is dissolved in the solvent. The chloride that is liberated reacts with the sodium hydroxide, reforming the sodium chloride that was the raw material for the manufacture of the chlorine used to make the phosgene. Other materials such as catalysts or other monomers may be added to the reacting mixture to control the molecular weight of the resin produced or to produce copolymers with better heat- or moisture-resistant properties than straight polycarbonates. (3) Since all raw materials can be produced at very high purities and since polymerization conditions are mild, the polycarbonate formation reactions are relatively clean and the formation of undesirable byproducts is minimized.

All commercial polycarbonate production is currently based on the phosgene chemistry described above. If alternate production routes could not be developed, substitution would occur at the product level: glass laminates would be the likely substitute in most glazing applications, and other plastics would be substituted elsewhere. Patents have been issued on chlorine-free routes to polycarbonates, however, and it has been reported that significant research and development activities are underway to commercialize such routes. (4) For this analysis, we assume that these activities will be technically successful, and that new production capacity based on carboxylation chemistry would be commercialized if the production of chlorine were banned. Available information suggests that process conditions would be much more severe and yields would be significantly lower than are achievable with a phosgene-based process, however, so that the resins would be more costly to produce. Our estimates of the net costs of substitution are summarized in Exhibit 3-23.

Exhibit 3-23. Benefits of Chlorine Chemistry in Polycarbonate Products (U.S. and Canada)

Estimated 1990 consumption (000 tons)	275
Substitute process	Carboxylation based
Estimated investment required ($Million)	550
Estimated incremental manufacturing costs ($Million/Year)	140
Estimated net costs of substitution ($Million/Year)	250

SOURCE: Charles River Associates, 1993.

Polycarbonate resins currently sell for about $2.50 per pound, a price that is considerably higher than that of glass and most other plastics with which they compete. They hold a significant market share in many applications because they possess desirable mechanical, electrical, and optical properties, including ease of fabrication. Since products made with the substitute process assumed have not been used commercially, it is not clear that they will have the same properties as the materials produced currently. If comparable properties cannot be obtained, consumers will lose some product utility and pay higher costs for products made from substitute materials.

References

(1) *Engineered Materials Handbook, Vol. 2 — Engineering Plastics*, ASM International, 1988, p. 151.

(2) "Polycarbonates: Tough Favorites," C. Verbanic, *Chemical Business*, December 1988, p. 36.

(3) *Kirk–Othmer Encyclopedia of Chemical Technology*, 2nd Ed., J. Wiley & Sons, 1963, Vol. 18.

(4) "Chlorine's Essential Role in Chemical Productions," D. Becher, 3rd Global Chlor-Alkali Symposium, Monaco, 1992.

Fluoropolymers

Fluoropolymers are a class of compounds that are polymers or copolymers of highly fluorinated monomer units. The most important fluoropolymer was introduced over 50 years ago, and is perhaps best known to consumers by the brand name Teflon® in its use in nonstick cookware. This material, and other compounds in the class, not only have low coefficients of friction (nonstick), but are resistant to attack by most chemicals and have excellent electrical and mechanical properties. They find widespread use in industrial and consumer applications where these properties are required, thereby justifying the relatively high price of the resins.

Fluoropolymer-based products are used in the aerospace and automotive industries to fabricate components that must resist fuels, oils, and other fluids at high temperatures. They are fabricated into a variety of types of equipment and components used in the chemical and petrochemical industries because their corrosion-resistant properties provide better service than many metallic alloys. Their low dielectric constant and mechanical properties that let them be formed into extremely thin films make them useful in electrical and electronic applications ranging from cable insulation to substrates for printed circuit boards. Their chemical stability, sterilizeability, and compatibility with physiological systems leads to their use in such medical products as sutures, catheters, surgical membranes, and cardiovascular and soft tissue patches. (1) While most fluoropolymers do not contain chlorine, the starting material for their synthesis is chloroform. This single-carbon, chlorine-containing compound is selectively fluorinated and polymerized to produce products of the desired composition and properties. (2)

A review of the properties of fluoropolymers and their applications and the properties of a number of other high-performance plastics leads us to believe the there are no reasonable direct substitutes in most applications. We reach this conclusion despite the fact that most fluoropolymer resins sell for $6 to $13 per pound, roughly twice as high or higher than most potential substitute resins. (3) This high price level has provided consumers with a significant incentive to attempt to use substitutes, even if twice as much or more is required, yet they have continued to use the fluoropolymers. If chlorine production were banned, consumers of these products would have three choices: do without the product; use the best available substitute and accept the decrease in performance; or use fluoropolymer products based on more expensive, chlorine-free manufacturing technology. We have evaluated the last choice because it appears consumers are willing to pay a substantial premium for access to performance products based on fluoropolymers.

It is possible to fluorinate organic compounds directly rather than carrying out the fluorination through chlorine-containing intermediates. The practical problem is that it is difficult to control such reactions to achieve the desired product properties, and yields tend to be low. A review of the literature on the chemistry of direct fluorination leads us to believe that carrying out the reactions in the presence of supercritical carbon dioxide and using other proprietary technology may serve as the basis of viable chlorine-free processes. (4) We estimate that, because of increased process complexity and severity and because of the decreased yields attainable, the manufacturing costs for products produced by such an approach would be at least $5 per pound higher than current costs. Based on an order-of-magnitude estimate of the capital requirements for such a process, we developed the estimates of the net cost of substitution shown in Exhibit 3-24.

Exhibit 3-24. Benefits of Chlorine in Fluoropolymer Products (U.S. and Canada)

Estimated 1990 production (000 tons)	22
Substitute process	Direct fluorination via supercritical CO_2
Estimated investment required ($Million)	110
Estimated incremental manufacturing costs ($Million/Year)	218
Estimated total cost of substitution ($Million/Year)	240

SOURCE: Charles River Associates, 1993.

By this estimate, the costs of fluoropolymer products to consumers could be increased by up to a factor of two. This would provide a still greater incentive to attempt to use substitutes with poorer properties, even if significant performance loss had to be accepted. The alternative, if consumers do not wish to bear the additional costs estimated here, is that they do without the use of fluoropolymer-based products and forego the benefits they currently enjoy from such use. Estimating the societal costs of such a response is beyond the scope of this study.

References

(1) *Engineering Materials Handbook, Vol. 2 — Engineering Plastics*, ASM International, 1988, p. 115.

(2) *Kirk–Othmer Encyclopedia of Chemical Technology*, 2nd Ed., J. Wiley & Sons, 1963, Vol. 9.

(3) "Fluoropolymers: Non Stick Growth," A. Loesel, *Chemical Marketing Reporter*, April 27, 1992, p. 24.

(4) "A New Route to Fluoropolymers," D. Rotman, *Chemical Week*, Sept. 2, 1992, p. 8.

Silicone Products

Products made from silicones are classified as fluids, elastomers, or resins, depending on their composition. They are generally expensive materials and have captured market share in many applications because of their superior performance. More than half of the silicone products are sold as fluids, which are chemically inert, resistant to attack by heat and oxidation, have low surface tension, and impart water repellency when applied as coatings. (1) They are used in cosmetic preparations such as shampoos and antiperspirants, pharmacological formulations, and a wide variety of industrial applications such as transformer fluids where inertness and stability are required. Their unique rheological properties make them useful in applications such as components of high-finish polishes and waxes for furniture and automobiles, and for antifoam agents and other industrial processing aids. (2)

Silicone elastomers are used mainly as adhesives and sealants where high performance is required. They are used to obtain durable, tight seals in metal-to-glass joints in buildings, for example, and for other difficult-to-seal joints in the construction and industrial sectors. These materials are used for automotive applications such as gaskets, seals, and O-rings, and for protecting electrical components. They may also be used in other electrical applications where their resistance to degradation provides extended service that justifies their high costs. (3) Silicone resins are used in applications requiring high thermal or chemical resistance, specific electrical properties, or water repellency. They are often copolymerized with other materials that are added to impart specific properties when used as coatings. They are important components of paints that must withstand harsh conditions such as exposure to high temperature or corrosion in marine environments. (4)

Most silicones are polymers of dimethyl siloxane, which is produced by the hydrolysis of dimethyl dichloro silane, although polymers of other organo siloxanes are produced as well. The chlorine-containing precursors are formed in reactions between silicon metal and methyl chloride or other chlorides that produce a mixture of compounds. Production of silicone fluids, elastomers, or resins is then achieved through control of the molecular weight of the product and the extent of copolymerization, if any, or the addition of other substitute groups to the polymer chain. (5) Since commercial production technologies are based on a chlorinated precursor, substitution for silicone products must occur at the product level. As is the case with other specialty performance materials that are based on chlorine chemistry, substitution may be imperfect.

We believe that a variety of lower-cost fluids such as mineral oils and alcohols, glycols, or organophosphorous compounds not based on chlorine chemistry could be substituted for liquid silicones, depending on the application. Because the lower-cost materials are not used now, we believe that replacement ratios would exceed unity, or they would not provide comparable performance in service because of decreased thermal resistance, for example. A variety of elastomers such as polyurethanes, olefinic thermoplastic vulcanates, copolyesters, acrylics, or ethylene propylene copolymers might be substituted for silicone elastomers, depending on the application, with some loss of utility. Specialty resins such as fluoropolymers, polyimides, or polyesters might be substituted for silicone resins, but again some loss of performance would be incurred. Our estimate of the net costs of substitution of these materials for silicone products is summarized in Exhibit 3-25.

Exhibit 3-25. Benefits of Chlorine in Silicone Products (U.S. and Canada)

Estimated 1990 Consumption (000 tons)	170
Substitutes	Various synthetic fluids, elastomers, or resins, depending on the application
Estimated investment required ($Million)	360
Estimated incremental cost of substitutes ($Million/Year)	458
Estimated net cost of substitution ($Million/Year)	530

SOURCE: Charles River Associates, 1993.

In most cases, the substitutes we have identified would not provide comparable performance to silicone products, even though the latter may cost as much as three to four times as much on a per-pound basis. If these substitutes were found to be unacceptable, it is possible that a substitute manufacturing process based on fluorine chemistry could be developed. Assuming it were possible to do so, significant investments would be required because of the difficult chemistry involved. Also, we would expect manufacturing costs to be higher because of the difficult chemistry, poor yields, and so on. If manufacturing costs for such a process were much more than about $1.5 per pound, or 30 percent higher than manufacturing costs based on existing technology (6), they would exceed the net costs estimated in Exhibit 3-26. This is yet another example of the benefits of chlorine in its role as a facilitator.

References

(1) *Engineered Materials Handbook, Vol. 2 — Engineering Plastics*, ASM International, p. 265.
(2) "Specialties '92: Silicones, A Global View," M. Shon, *Chemical Marketing Reporter*, April 27, 1992, p. 18.
(3) *1991 Rubber Red Book*, 43rd Ed., Communications Channels Inc., p. 436.
(4) "Silicone Elastomers," R. Frye, *Rubber World*, February 1992, p. 16.
(5) *Silicones: Chemistry and Technology*, G. Koermer et al., CRC Press, 1991.
(6) "Specialties '91: Silicones," A. Loesel, *Chemical Marketing Reporter*, April 29, 1991, p. 37.

Summary of the Benefits of Chlorine as a Facilitator

The net benefits of chlorine as a facilitator in the products evaluated here are estimated to be $56.7 billion per year and investments of about $5.5 billion would be required to produce the substitutes. The greatest benefits arise from the role chlorine chemistry plays in the manufacture of pharmaceutical products. The pharmaceutical industry consumes about one percent of current chlorine production, but the value of the products derived from chlorine exceeds the value of the chlorine itself by more than three orders of magnitude. A comparable ratio of net consumer benefits to the cost of chlorine consumed was also found in crop protection chemicals, and benefit-to-cost ratios in the range of 5 to 10 are found for most of the other products evaluated here.

These examples illustrate the benefits that chlorine can bring to the consumer even though the consumer is unaware of chlorine's role in the manufacture of the products consumed.

The Benefits of Chlorine in Other Products

As shown in Exhibits 2-2 through 2-4, a significant amount of chlorine and its coproducts are consumed in uses that cannot be defined well because they are so varied. Our methodology for estimating the benefits of sodium and potassium hydroxides should capture these miscellaneous uses since we have estimated the benefits of the *total* production of these materials. We have not captured the benefits of the total production and use of chlorine, however, choosing instead to focus on the major uses that have been identified in various market surveys. The amount of chlorine identified here as being consumed directly, incorporated into products, or used as a facilitator sums to about 90 percent of the estimated total chlorine consumption in 1990. The majority of the unidentified uses are in chlorine consumption for the manufacture of various inorganic and organic materials, in applications where it is used as a facilitator and where it is contained in the product.

Various chlorine-containing sulfur and phosphorous compounds are used as intermediates in the manufacture of other organic compounds that are used as dyes, hydraulic compounds, gasoline additives, and anti-oxidants. Others include various metal chlorides that are consumed directly and used in products such as batteries, cosmetic preparations, and flocculating agents. Some of these compounds are also used as intermediates in the manufacture of crop protection chemicals and pharmaceuticals, and their consumption has been captured in the benefits estimates for those products.

Relatively large amounts of chlorine are consumed in the manufacture of innumerable organic compounds. These products, in turn, are used as surfactants and detergents, as dyes and cosmetics, in food products and clothing, and in a myriad of other products used in the industrial sector and by consumers. Some are consumed in the manufacture of pharmaceuticals and crop protection chemicals, but most are used in other sectors, as shown by the product tree in

Appendix B. Relatively small amounts of chlorine are consumed in the manufacture of titanium metal, but production is critically dependent on the use of chlorine since the metal is produced by reduction of purified titanium tetrachloride. Use of chlorine is also essential to the production of other reactive metals that, along with titanium, are critical materials in the aerospace and other manufacturing industries.

We assert, by the same logic developed in all of the examples cited earlier in this chapter, that the use of these materials provides significant benefits to consumers. Furthermore, the benefits are generally large relative to the amount of chlorine consumed. Relatively little chlorine is consumed, for example, in the manufacture of catalysts. However, catalysts based on aluminum, vanadium, copper, and titanium chlorides facilitate the production of billions of pounds of consumer products. All polyolefins, for example, are produced using either chlorine-containing Ziegler–Natta catalysts or the newer metallocene catalyst systems that are synthesized from chlorine-containing precursors. Elimination of these catalysts would increase the costs of polyolefin products, and it is not clear that the products produced with substitute catalysts would have the same properties or performance characteristics.

Very small amounts of chlorine are consumed in the manufacture of the chlorosilanes that are used in the semiconductor industry. Yet these compounds are critical to the manufacture of high-performance, high-density integrated circuits that are the foundation for modern electronics. Use of chlorosilanes allows chip manufacturers to deposit near-perfect epitaxial layers of silicon on the starting wafers and subsequently produce defect-free circuits on top of this layer. Substitute compounds based on fluorine chemistry have been used in the past, but they apparently do not produce the quality necessary for current designs at comparable costs.

CRA did not estimate the benefits of chlorine chemistry in applications such as semiconductor manufacture and catalysts. The information required for the analyses is highly proprietary and the effects of substitutes on product properties are largely unknown. However, based on the volume of sales of computers and other microelectronic-based products and of catalyst-based synthetic polymers and other materials, we believe that the magnitude of the benefits will be in the billions of dollars per year.

Benefits to Consumers in the United States and Canada

The benefits estimated in the preceding sections of this chapter are based on the total consumption of the products in the United States and Canada. The benefits of chlorine chemistry in a product will accrue to the consumers who actually use it, and where information is available on consumption in each country, it is possible to allocate benefits to consumers in each.

In many cases, data were available on product consumption in the United States and Canada, while in other cases data were available from U.S. consumption only. In these cases we used our best judgments to estimate Canadian consumption, usually basing them on the relative populations or Gross Domestic Products (GDP) in 1990. In other cases, the location of the consumption was known, but this does not give the location of benefits directly. Relatively more chlorine is consumed per capita in pulp manufacture in Canada than in the United States, for example, because of the importance of the forest products industry there. But the benefits of its use accrue to the users of the products produced *from* the pulp, not the pulp itself, so that the benefits may accrue to consumers in other regions where data on the consumption of the final product were not readily available (e.g., the paper made from the pulp), we have based our estimate of benefits on the production and consumption of the first chlorine-based product.

Based on the data available and our estimates of the consumption of the products in the two countries, we have estimated the distribution of benefits as shown in Exhibit 3-26.

Exhibit 3-26. Estimated Benefits of Chlorine Chemistry to Consumers in the United States and Canada

Use or Application	Estimated Net Benefits ($Million/Year)	
	United States	Canada
Direct Uses		
Pulp bleaching	2,100	260
Water treatment	5,430	570
Sodium hydroxide	2,110	400
Potassium hydroxide	120	10
In Products		
PVC products	6,125	765
Chlorinated solvents	1,210	140
Hydrogen chloride	400	60
Bleaches, etc.	740	60
Flame retardants	160	20
Polychloroprene	360	20
Crop protection	22,140	2,160
Chlorinated polyolefins	110	10
Polyvinylidine chloride	160	20
As a Facilitator		
Propylene oxide	170	20
Epichlorohydrin	435	45
Isocyanates	345	35
Titanium dioxide	470	10
Fluoropolymers	220	20
Polycarbonates	225	25
Pharmaceuticals	47,010	6,590
Refrigerants	500	50
Silicones	480	50
Total	91,020	11,340

SOURCE: Charles River Associates, 1993.

The distribution of total benefits between the two countries is roughly proportional to the population, as would be expected. Relatively more of the benefits of pharmaceuticals accrue to Canadian consumers, because pharmaceuticals claim a higher share of total healthcare expenditures there than is the case in the United States. On the other hand, relatively less of the benefits of titanium dioxide accrue to Canadian consumers because a larger share of production using the sulfuric acid process already occurs there. The benefits of most other uses or applications are based on consumption ratios that are about nine to ten times higher in the United States than in Canada.

4
Economic Contributions

When consumers purchase specific products based on chlorine chemistry, they enjoy certain benefits that would be diminished if these products were no longer available. CRA's quantitative assessment of these benefits was presented in Chapter 3. But chlorine-dependent industries also contribute to the economic welfare of society in other ways as well. By investing in plant and equipment, employing workers, and purchasing raw materials and other supplies, they generate a significant volume of economic transactions that become part of a region's stock of wealth and annual flow of income. We have assessed the 1990 economic contributions of these industries by estimating a number of these key parameters, and have found that chlorine-dependent industries:

- Generated almost $80 billion per year of annual sales;
- Employed nearly 400,000 workers directly and nearly 1.4 million workers in total;
- Paid wages for these workers amounting to over $33 billion per year;
- Had plants that operate in 48 U.S. states and in nine Canadian provinces;
- Maintained facilities with an aggregate investment value of over $61 billion; and
- Contributed more than $3.0 billion per year to the net balance of foreign trade.

These results are summarized in Exhibit 4-1, which shows the contributions that accrued to the economies of the United States and Canada individually. The remainder of this chapter presents our methodology and our detailed findings of economic contributions in terms of:

- Value of sales,
- Employment and wages,
- Investment, and
- Foreign trade.

Exhibit 4-1. Estimated 1990 Economic Contributions of Chlorine-Dependent Industries

	Units	United States	Canada	Total
Value of sales	$Billion/Year	71.4	8.5	79.9
Processing plants	Plants	718	103	821
PVC fabrication plants	Plants	2,530	215	2,745
Total plants	Plants	3,248	318	3,566
Employment, direct	Workers	366,700	28,400	395,100
Employment, indirect	Workers	948,300	55,600	1,003,900
Employment, total	Workers	1,315,000	84,000	1,399,000
Wages, direct	$Billion/Year	9.9	0.8	10.7
Wages, indirect	$Billion/Year	21.4	1.5	22.9
Wages, total	$Billion/Year	31.3	2.3	33.6
Gross domestic investment	$Billion	56.8	4.4	61.2
Balance of trade	$Billion/Year	+2.9	+0.1	+3.0

SOURCE: Charles River Associates, 1993.

METHODOLOGY FOR MEASURING THE CHLORINE-DEPENDENT INDUSTRY'S ECONOMIC CONTRIBUTIONS

For this study, CRA used a very conservative approach to define the industries and jobs that depend on chlorine chemistry. To achieve this narrow definition of economic contributions, we determined the point in the production chain where the economic activity is critically dependent on chlor-alkali-derived products and where such activity is incidental to the chlor-alkali industry. These limits are process- and material-specific, and defining them is somewhat subjective. However, in estimating direct contributions, we used this major criterion: *a manufacturing activity is counted in the chlorine-dependent industry if, in the absence of chlorine, the manufacturing activity would be forced to shut down.*

For example, producers of ethylene dichloride, vinyl chloride monomer, and polyvinyl chloride resin are included in the industry because their output contains chlorine. However, the producers of products derived *from* polyvinyl chloride resin may or may not be included in the analysis depending on whether the manufacturer could substitute another material and remain in business. For example, producers of fabricated PVC products such as film and sheet who could substitute other resins (for example, polyolefins) by modifying their fabrication equipment would *not* be considered because they would continue to exist in the absence of chlorine. Producers of other PVC fabricated products such as large-diameter pipe, however, *would* be considered as contributing to the industry because the substitute product, ductile iron pipe, could not be made in their facilities and they could not remain in business in the absence of the PVC resin.

For the pulp and paper industry, we followed a similar conservative definition: only the bleaching activities of the mills are considered in the economic contributions analysis. A shift to chlorine-free bleaching processes may involve retrofitting existing mills or building completely new facilities. These decisions will be made on a site-specific basis. However, in either case, the final products of the industry will continue to be supplied to the marketplace.

In all cases, we assumed that existing distribution and retail sales networks will be capable of supporting the movement of substitute products, and these networks have *not* been included in CRA's estimates of economic contributions. We also did not take into account the significant dislocations that would occur in the distribution networks, and so our estimate of economic contributions is understated.

To measure chlorine-dependent economic contributions, CRA applied the following methodology:

- CRA identified over 800 specific manufacturing facilities that depend on chlorine and an additional 2,700 facilities that fabricate PVC resin.

- For each of the specific facilities, CRA assembled a database containing information regarding the primary products produced at that site, the capacity of the plant, and the number of employees.

- At the state and national level, CRA collected information on average annual earnings for workers by industry.

- At the national level, CRA collected information on gross domestic investment and developed a methodology to apportion these values to the chlorine-dependent industries at the local level.

- At the national level, CRA collected information on the imports and exports of chlorine-based products in order to estimate the industry's contribution to the balance of merchandise trade.

ECONOMIC CONTRIBUTIONS FROM VALUE OF SALES

CRA estimates that chlorine-dependent industries generate sales of almost $80 billion per year. In order to appreciate the diversity of the economic sectors involved in these sales, we have characterized the value of sales into the same three categories described in Chapter 3:

- Direct consumption,
- Chlorine-containing products, and
- Chlorine-facilitated products.

CRA established three primary objectives for measuring the value of sales:

- First, the *definition of value* should be clear: *there should be no double counting in the estimate*. Economic studies of other industries have tended to inflate the value of sales by counting sales of raw materials, intermediate products, final products, equipment, and other expandables, thus greatly exaggerating the importance of an industry. CRA eliminates this problem by measuring the value of sales only once. (This methodology is conservative and underestimates the total value that these products provide as they ripple through the economy. To address this issue, we discuss an alternative "macroeconomic" measure of value as described in the next chapter.)

- Second, the *measurement of value* should occur as close as possible to the point of potential chlorine substitution, which also results in a conservative estimate because we do not consider any value-added contributions through further processing steps.

- Third, the *unit of association* should be based on clearly identifiable plants whenever possible. This will minimize the use of "SIC code" data, which does not distinguish distinct chlorine-using plants at a fine level of detail nor identify the nature of the chlorine compound's use. If this plant-level detailed data can be cross-checked with publicly available data from other sources, it becomes more reliable and credible for the public policy issues that may be raised regarding a possible chlorine ban.

With these objectives in mind, CRA's methodology for measuring the value of sales is as follows. For direct consumption and for applications where chlorine is contained on the molecule, CRA determined the *earliest point* in the chain between producers and consumers at which product substitution would occur for each chlorine derivative selected for analysis. CRA then collected information on the amount of product consumed (often by type of end use), and the relevant market prices for 1990. The value of sales equals the quantity consumed (often by type of end use) times the market price. For example, the data for PVC included the quantity consumed and market price for each of the following end uses: pipe, siding, windows, wire and cable, flooring, other calendered products, film and sheet, plastic bottles, adhesives, and all other uses.

For chlorine used as a facilitator, CRA determined the earliest point in the production chain at which *process substitution* would occur that results in a product that does not contain chlorine. This approach resulted in CRA surveying these uses of chlorine to understand how chlorine is used in each of these technological applications: as a process solvent, as a chemical intermediate, as a catalyst, and so on. With this information in hand, CRA collected data on the percentage of total production for each product that was based on chlorine, the quantity consumed, and the market price of the final product. The value of sales equals the percentage of production based on chlorine times the quantity consumed times the market price. For example, the data for titanium dioxide indicated that 80 percent of U.S. and Canadian productive capacity is based on chlorine with the remainder based on sulfuric acid. CRA used this percentage to determine the appropriate value of sales of chlorine-based titanium dioxide.

In this analysis we are interested in determining the total sales of all chlorine-dependent products in each product category. Therefore, consumption in some categories is higher than were reported in the benefits estimates. The additional products included are noted in these instances.

Value of Sales for Direct Chlorine Consumption

The following discussion highlights CRA's analysis of the value of sales for direct uses. CRA estimates that the value of sales for the four direct uses described in more detail below amounted to approximately $4.9 billion in 1990, as shown in Exhibit 4-2.

Exhibit 4-2. Estimated 1990 Sales of Chlor-Alkali Products Consumed Directly (U.S. and Canada)

Chlor-Alkali Products	Consumption (000 tons)	Value of Sales ($Million)
Pulp bleaching[1]	2,920	600
Water treatment[2]	620	70
Sodium hydroxide[3]	13,100	4,050
Potassium hydroxide[3]	360	190
Total		4,910

Notes:
(1) Includes chlorine and sodium chlorate.
(2) Includes sales of chlorine for potable and wastewater treatment.
(3) Includes all sales of this product.

SOURCE: Charles River Associates, 1993.

Pulp and Paper

The pulp and paper industry uses chlorine and chlorine-based compounds primarily for bleaching applications. As we discussed in Chapter 3, the pulp and paper industry is converting to technology that will substantially diminish its use of chlorine and increase its use of chlorine dioxide. At the current time, industry operating practices are undergoing review that may result in further changes in chlorine-based technology. CRA estimates that the value of sales of chlorine and chlorine-based compounds amounted to $600 million in 1990. These sales are likely to be less in the future because of the emerging technology and market changes occurring in this industry.

Economic Contributions

Water Treatment

Chlorine is used to treat drinking water supplies and wastewater. More than 98 percent of the U.S. drinking water supply and most of the Canadian water supply is disinfected with chlorine or chlorine derivatives. Even though water treatment represents a significant and well-recognized direct use of chlorine, it consumes only modest amounts of the product (620,000 tons) and buys chlorine at market prices that do not reflect its value in use. CRA estimates that the value of sales of chlorine used for water treatment in the United States and Canada amounted to $70 million in 1990.

Sodium Hydroxide

By far the largest direct use of a chlor-alkali product is represented by sodium hydroxide. Its many uses include alumina manufacturing, neutralizing waste streams, and the manufacture of soaps and detergents. U.S. and Canadian sodium hydroxide consumption exceeded 13 million tons in 1990. For purposes of this research, CRA classified all consumption of sodium hydroxide as direct consumption, and we estimated the value of sales of sodium hydroxide in all of its end uses in 1990 at over $4.0 billion.

Potassium Hydroxide

Potassium hydroxide is the alkali coproduct generated when potassium salts are used instead of sodium salts in the electrolytic production of chlorine. As discussed in Chapter 3, potassium hydroxide is primarily used in specific applications for which sodium hydroxide does not produce the desired properties, like specialty glass manufacture and liquid soaps and detergents. CRA estimates that the value of sales of potassium hydroxide amounted to $190 million in 1990.

Value of Sales for Chlorine-Containing Products

The following discussion highlights CRA's analysis of the value of sales for chlorine-containing products. CRA estimates that the value of sales for the ten chlorine-containing products examined here amounted to over $15.1 billion in 1990 (see Exhibit 4-3).

Exhibit 4-3. Estimated 1990 Sales of Chlorine-Containing Products (U.S. and Canada)

Chlorine-Containing Products	Consumption (000 tons)	Value of Sales ($Million)
PVC	4,200	3,840
Chlorinated solvents[1]	794	690
Hydrogen chloride[2]	980	60
Bleaches[3]	436	690
Polychloroprene	87	260
Crop protection chemicals	-	7,960
Flame retardants[4]	93	260
Chlorinated polyolefins	85	340
Polyvinylidine chloride	56	160
Refrigerants[5]	373	840
Total		15,100

Notes:

(1) Includes all identified uses for chlorinated solvents.
(2) Includes only merchant sales. There is a significant volume of captive consumption.
(3) Includes sodium hypochlorite, calcium hypochlorite, and chlorinated isocyanurates.
(4) Includes brominated, chlorinated, and halophosphate compounds.
(5) Includes F-11, F-12, F-22, and other similar products.

SOURCE: Charles River Associates, 1993.

Economic Contributions

Polyvinyl Chloride

Chlorine's largest single outlet is in the manufacture of polyvinyl chloride (PVC) resin. This versatile plastic product is used in numerous fabricated products, as shown in Exhibit 4-4 and the product tree in Appendix B. Most applications are for durable goods that have a very long period of service, in some cases upwards of 20 years or more. U.S. and Canadian consumption of PVC amounted to 4.2 million tons in 1990, making it one of the top-selling thermoplastic resins. CRA estimates that the value of sales of PVC products amounts to more than $3.8 billion in 1990.

Exhibit 4-4. Typical Products Made from PVC

Household Items	Building and Construction	Automotive	Medical
Raincoats	Sewer and drain pipe	Upholstery	Blood bags
Handbags	Flooring	Floor mats	Tubing
Toys	Electrical conduits	Roof tops	Sheeting
Shower curtains	Weather stripping	Instrument panels	Packaging

SOURCE: Charles River Associates, 1993.

Chlorinated Solvents

Another large outlet for chlorine is in a group of products called chlorinated solvents. Over 910,000 tons of these products were consumed in the United States in 1988, but consumption was estimated to have dropped to about 720,000 tons in 1990. For purposes of this study, CRA collected data on sales and use of these products for each major application: for dry cleaning, for degreasing and special parts cleaning, for paint stripping and adhesives, and for use as a process solvent. Exhibit 4-5 summarizes these end uses. We estimate that the value of sales of 794,000 tons of chlorinated solvents in the United States and Canada amounted to $690 million in 1990. Some chlorinated solvents have the potential to deplete stratospheric ozone and are being phased out under the Montreal Protoc ls. Others have no ozone-depleting potential but may have other health and safety effects if not used properly. As a result, some of the end users are currently converting to alternative processes or solvent systems not based on chlorine. Sales of certain chlorine-based products into this industry will diminish in the future.

Exhibit 4-5. Estimated 1990 U.S. Chlorinated Solvent Consumption (000 tons)

Industry	Trichloro-ethylene	Perchloro-ethylene	Methylene Chloride	1,1,1-Trichloro-ethane	CFC-113	Total
Adhesives	0	0	6	29	0	35
Aerosols	0	3	22	38	1.	64
Chemical intermediates	9	7	0	24	6	46
Dry cleaning	0	148	0	0	2	150
Electronics	3	1	18	18	44	84
Flexible foams	0	0	26	3	0	29
Paint stripping	0	0	73	0	0	73
Parts cleaning	53	30	16	181	32	312
Pharmaceuticals	0	0	16	0	0	16
Textiles, coatings, inks, and others	1	20	39	43	1	104
Total	66	209	216	336	86	913
Percent Reduction, 1988–1991	36.5	51.3	38.2	11.7	43	31.8

Note: Uses included in this table are broader than those identified in Chapter 3.

SOURCE: *Potential for Source Reduction and Recycling of Halogenated Solvents: Summary Report and Technical Support Documents* by the Source Reduction Research Partnership, 1988.

Hydrogen Chloride

This product has a wide variety of uses: steel pickling, oil well acidizing, food preparation (particularly high fructose corn syrup), and calcium chloride manufacturing. A great deal of hydrogen chloride is produced as a byproduct, and the remainder is produced intentionally as burner acid. Most hydrogen chloride is consumed in aqueous form as hydrochloric acid. As much as 80 percent of the hydrochloric acid produced does not enter the merchant market, but is used on-site in other processes or is neutralized and disposed. Production and consumption, therefore, can be vastly different. CRA estimates that merchant sales of hydrogen chloride were almost one million tons in 1990, and that the value of sales of this product amounted to $60 million.

Bleaches, Disinfectants, and Pool Chemicals

The chlorine applications that consumers are probably most familiar with are laundry bleaches, disinfectants, and pool chemicals. For reporting purposes, we have incorporated these products into one category, but CRA's evaluation considered the major products and applications separately. The major chlorine compounds used are sodium hypochlorite, calcium hypochlorite, and the chlorinated isocyanurates. Almost 440,000 tons of these products were consumed in 1990. CRA estimates that the value of sales of these bleach and pool chemicals amounted to $690 million in 1990.

Polychloroprene

This product is a performance polymer used in applications that require high strength, high heat and oil resistance, and elasticity. Major applications include electrical insulation and sheathing material, sealants, conveyor belts and transmission belts, and flexible hoses. Automobile fan belts are generally made from this material. Approximately 87,000 tons of this product were sold in 1990. CRA estimates that the value of sales of polychloroprene amounted to $260 million in 1990.

Crop Protection Chemicals

Despite the fact that a small number of earlier generations of heavily chlorinated crop protection chemicals have been banned, chlorine is still indispensable in the manufacture of the currently approved roster of products that serve this industry. CRA surveyed approximately 180 of the top-selling crop protection chemicals, as shown in Exhibit 4-6. In most cases, chlorine appears as an active ingredient on the molecule, and in other cases it is only used in the synthesis of the final product. These products are used extensively in U.S. and Canadian agriculture to enhance crop yield. Total bulk sales of crop protection chemicals in U.S. agriculture amounted to nearly $5.7 billion in 1990. CRA's survey covered the products whose volume of sales was $4.6 billion, or more than 80 percent of the total. The survey indicated that 100 percent of all herbicides, 87 percent of all insecticides, 96 percent of all fungicides, and 85 percent of other crop protecti n chemicals depend on chlorine chemistry. In addition, these products are widely used for nonagricultural purposes by governmental and institutional customers and homeowners. Total sales of these products in *all* uses in the United States and Canada amounted to over $8.2 billion. On the basis of this analysis, CRA estimates that the value of sales of chlorine-dependent crop protection chemicals amounted to almost $8.0 billion in 1990.

Exhibit 4-6. Estimated 1990 Chlorine Use for Crop Protection Chemicals

Type of Product	Number of Products Surveyed	1990 Total Sales of Surveyed Products ($Billion)[1]	Percent Chlorine Involvement		
			On the Molecule	In the Synthesis	None
Herbicides	62	2.84	60	40	0
Insecticides	42	1.13	40	47	13
Fungicides	39	0.43	52	44	4
Others	41	0.22	62	23	15
Total	184	4.62	54	42	4

Note:

(1) Sales from chemicals producers; sales of formulated products are higher.

SOURCE: Charles River Associates, 1993.

Flame Retardants

This class of products consists of brominated, chlorinated, and halophosphate compounds that are generally mixed with other materials (often plastics or fibers) to enhance product safety. For example, the plastics used in televisions and personal computers may be subjected to high heat for extended periods of time and require the use of these additives. Over 90,000 tons of these compounds were consumed in 1990. CRA estimates that the value of sales of flame-retardant products was $260 million in 1990.

Chlorinated Polyolefins

This class of products are generally used in applications that require flexibility and flame retardance. These materials have excellent physical and chemical properties, including toughness and resistance to weather, heat, oil, and corrosive chemicals. They are often found in electrical wire and cable for household and automotive applications, gaskets and seals, pond liners, and geomembranes. Approximately

85,000 tons of these products were consumed in 1990. CRA estimates that the value of sales of these products amounted to $340 million in that year.

Polyvinylidine Chloride

Polyvinylidine chloride (PVDC) is primarily used in packaging applications because of its barrier and strength properties. It is tough and transparent, has low moisture and air permeation rates, and good shrinkage and vacuum packing characteristics. Consumers use it to wrap meats, vegetables, pastries, and leftovers. Over 55,000 tons of PVDC were consumed in 1990 at a value of sales of $160 million.

Refrigerants

Chlorine is used in the manufacture of chlorofluorocarbon (CFC) refrigerants that are being phased out under the Montreal Protocols. The fact that the substitute refrigerants are just beginning to enter the market attests to the difficulty in finding suitable replacements for the banned products, and it is uncertain what the share of chlorine-based products will be in the future. Some of the substitute products contain chlorine (e.g., the HCFCs), while other substitutes use chlorine only in the manufacturing process. Some of the new substitute refrigerants actually use more chlorine in manufacturing than the banned products.

The issue of phasing out CFCs has been intensely studied and has received close regulatory scrutiny over the past decade and beyond. Converting to new refrigerants will require substantial investment in research and development for new products, new process equipment (since there is no technology for drop-in replacements), and new infrastructure to support both the obsolete and the new refrigeration industry. For purposes of this analysis, CRA collected data on the size of the CFC market in 1990, knowing that this particular industry was in the midst of tremendous technological change. Nearly 375,000 tons of CFCs were consumed in 1990, and CRA estimates that their value of sales amounted to $840 million. Given the rapid technological change occurring in this industry, sales of chlorine-based products into this industry may be lower in the future.

Value of Sales for Chlorine Used as a Facilitator

The following discussion highlights CRA's analysis of products and processes where chlorine is used primarily as a facilitator and does not end up in the final product. These technologies and their alternatives were discussed in detail in Chapter 3.

CRA estimates that the value of sales for the eight applications (described in detail below) in which chlorine primarily acts as a facilitator amounted to almost $59.9 billion in 1990 (see Exhibit 4-7).

Exhibit 4-7. Estimated 1990 Sales of Chlorine Used as a Facilitator (U.S. and Canada)

	Consumption (000 tons)	Value of Sales ($Million)
Propylene oxide[1]	535	580
Isocyanates[2]	745	1,400
Epichlorohydrin[3]	258	740
Titanium dioxide[4]	740	1,540
Pharmaceuticals[5]	-	51,800
Polycarbonates	275	1,160
Fluoropolymers	22	280
Silicones[6]	170	1,990
Miscellaneous	-	390
Total		59,880

Notes:

(1) Represents only the estimated quantity and value of the chlorohydrin-based material.
(2) Includes TDI, MDI, and PMDI applications.
(3) Includes use in epoxy resins, polyamines, elastomers, and other.
(4) Represents only the estimated quantity and value of the chloride-based material.
(5) Represents 84.5% of total pharmaceutical sales.
(6) Includes silicone fluids, elastomers, and resins.

SOURCE: Charles River Associates, 1993.

Propylene Oxide

Approximately 45 percent of propylene oxide capacity in the United States and Canada uses chlorohydrin-based technology. The remaining 55 percent is based on peroxidation technology. Propylene oxide is used to make a variety of consumer and industrial products. As shown in Exhibit 4-8, nearly 60 percent of propylene oxide consumption is used in conjunction with isocyanates to make polyurethanes. Almost 25 percent of propylene oxide is used to make propylene glycol and its derivatives, while the remaining 15 percent is used in a number of diverse applications. Consumer end uses for propylene oxide derivatives include furniture cushions, insulation in refrigerator doors, automobile bumpers, cosmetics, and latex paints. After taking into account only chlorine's market share, CRA estimates that the value of sales of chlorine-based propylene oxide amounted to $580 million in 1990.

Exhibit 4-8. Propylene Oxide Uses

Percent of Propylene Oxide Consumption	Derivative	Typical Applications
60	Polyurethanes	Flexible foams: furniture, car seats, carpet underlay, bedding Rigid foam: construction, refrigeration, insulation Nonfoam: spandex fibers, adhesives, surface coatings, automobile bumpers
25	Propylene glycol	Unsaturated polyester resins: transportation, recreational vehicles, boats Personal care products: cosmetics, pharmaceuticals, human food Functional fluids: aircraft de-icers, specialty antifreeze Paints and coatings: water-based semigloss and gloss enamels
15	Miscellaneous	Other glycols: solvents, flotation chemicals, cleaning fluids Nonurethane polyether polyols: surfactants, functional fluids, lubricants

SOURCE: Charles River Associates, 1993.

Polymeric Isocyanates

Polymeric isocyanates are used in conjunction with propylene oxide to make polyurethanes, which then go into a variety of consumer and industrial applications like flexible and rigid foam insulation, automobile bumpers, furniture and bedding, coatings and adhesives, and specialty elastomers. Spandex stretch fibers sold under the Lycra® brand are produced from these chemicals. All U.S. and Canadian production of isocyanates is based on chlorine chemistry. The major products are TDI (toluene diisocyanate) and MDI (methylene diphenyl diisocyanate). Approximately 330,000 tons of TDI and 400,000 tons of MDI were consumed in 1990. CRA estimates that their value of sales amounted to approximately $1.4 billion in 1990.

Epichlorohydrin-based Products

Epichlorohydrin is used in the manufacture of epoxy resins, polyamines, specialty elastomers, and certain other applications. All U.S. and Canadian production of epichlorohydrin products is based on chlorine chemistry. As shown in Exhibit 4-9, over 250,000 tons of epoxy resins were consumed in 1990, and nearly 50,000 tons of other epichlorohydrin-based products. CRA estimates that the value of sales of epichlorohydrin products (primarily epoxy resins) amounted to $740 million in 1990.

Exhibit 4-9. Estimated 1990 Sales of Epichlorohydrin-based Products (U.S. and Canada)

	Consumption (000 tons)	Value of Sales ($Million)
Epoxy resins	208	585
Polyamines	15	75
Wet-strength resins	14	20
Elastomers	21	60
Total		740

SOURCE: Charles River Associates, 1993.

Titanium Dioxide

Titanium dioxide manufacture has been shifting over the past few decades toward chloride-based technology and away from sulfate-based technology (see Chapter 3 for more details). In 1990, approximately 80 percent of U.S. and Canadian capacity was based on chlorine, and consumption amounted to nearly one million tons. Titanium dioxide is most commonly used as a white pigment and for opacity in paint, paper, plastics, and other applications. CRA estimates that the value of sales of chlorine-based titanium dioxide amounted to over $1.5 billion in 1990.

Pharmaceutical Products

Although the pharmaceutical industry purchases only modest quantities of chlorine, CRA's research indicates that chlorine is a critical material in the manufacture of many of the leading pharmaceutical products. CRA surveyed approximately 206 of the top-selling pharmaceutical products classified into 12 standard therapeutic classes, as shown in Exhibit 4-10. As discussed in detail in Chapter 3, chlorine appears as an active ingredient on the molecule in about

20 percent of the products, and in about 58 percent more in the synthesis of the final product. Chlorine appears as the hydrochloride in an additional six percent of these products. Therefore, almost 85 percent of the surveyed pharmaceuticals involved chlorine chemistry in one form or another.

Sales of all pharmaceutical products in the United States in 1990 amounted to an estimated $54.6 billion, while the sales of the products we surveyed were $25 billion. Sales of pharmaceutical products in Canada amounted to an additional $6.7 billion. Thus, CRA's research covered somewhat more than 40 percent of all pharmaceutical sales. Given our market survey results, we have assumed that 84.5 percent of pharmaceutical products depend on chlorine chemistry. On the basis of this analysis, CRA estimates that the value of sales of chlorine-dependent pharmaceutical products amounted to almost $51.8 billion in 1990.

Exhibit 4-10. Estimated 1990 Chlorine Use in Surveyed Pharmaceuticals

Therapeutic Class	Number of Products Surveyed	Sales ($Million)	Percent of Sales	
			Chlorine-Dependent	No Chlorine Involved
Nutritionals	8	487	92	8
Blood modifiers	7	785	46	54
Hormones	20	2,038	71	29
Cardiovasculars	43	6,354	78	22
Respiratory drugs	16	1,666	79	21
Central nervous system drugs	39	5,255	92	8
Gastrointestinals	9	2,513	98	2
Anti-infectives	36	3,955	93	7
Biologicals	4	205	0	100
Topicals	12	854	95	5
Antineoplastics	6	468	62	38
Miscellaneous	6	460	80	20
TOTAL	206	25,040	84	16

SOURCE: Charles River Associates, 1993.

Polycarbonate Resins

Polycarbonates are high-performance polymers used in products familiar to consumers: compact disks, bulletproof "glass," electronics, business machines, appliances, and automobiles. At the current time, all North American production of polycarbonates is based on chlorine chemistry, although there are reports of potential alternative routes in other parts of the world. CRA estimates that about 275,000 tons of polycarbonate resins were consumed in 1990 and that the value of sales of these resins amounted to $1.16 billion.

Fluoropolymers

Fluoropolymers are high-performance specialty polymers used in diverse applications like protective coatings (nonstick cookware; pipe and tubing in corrosive environments) and wire and cable. It's also used in aerospace, industrial, and mechanical products. All U.S. and Canadian fluoropolymer production is based on chlorine chemistry. Approximately 22,000 tons of these products were consumed in 1990 for a value of sales of $280 million.

Silicone Products

Silicone products are used in a variety of high-performance applications such as heat transfer fluids and specialty resins, elastomers, and adhesives. These products are commonly found in automotive, building and construction, and consumer electronic applications. At the current time, all U.S. and Canadian production of silicone products is based on chlorine chemistry. In 1990, 170,000 tons of silicones were consumed, and CRA estimated their value of sales at almost $2 billion.

Miscellaneous

In this category, CRA accounts for the contribution of some chlorine-derived products not covered in detail elsewhere in this analysis. These particular materials have been included because data were available both on their consumption and market prices. These products and their sales values are shown in Exhibit 4-11. CRA estimates that their 1990 sales value totaled $400 million. As shown in the product trees in Appendix B, there are hundreds of other materials whose sales values have not been included because data on consumption or prices were not available. In the aggregate they represent a significant additional contribution of the chlorine-dependent industries that has not been included in this analysis.

Exhibit 4-11. Estimated 1990 Sales of Miscellaneous Chlorine-Derived Products (U.S. and Canada)

Product	Value of Sales ($Million)
Bromine not included elsewhere	100
Chlorinated paraffins	50
Phosgene not included elsewhere	40
Zinc chloride	10
Carboxymethylcellulose	110
Benzyl chloride	50
Aluminum chloride	30
Total	390

SOURCE: Charles River Associates, 1993.

The distribution of sales between the United States and Canada is shown in Exhibit 4-12.

Exhibit 4-12. Estimated 1990 Value of Sales of Chlorine-Dependent Products in the United States and Canada

Use or Application	Estimated Value of Sales ($Million)	
	United States	Canada
Direct uses		
Pulp bleaching	420	180
Water treatment	65	5
Sodium hydroxide	3,530	520
Potassium hydroxide	175	15
In products		
PVC products	3,430	410
Chlorinated solvents	620	70
Hydrogen chloride	55	5
Bleaches, etc.	650	40
Flame retardants	225	35
Polychloroprene	250	10
Crop protection	7,240	720
Chlorinated polyolefins	310	30
Vinylidine chloride	145	15
Refrigerants	770	70
As a facilitator		
Propylene oxide	550	30
Epichlorohydrin	670	70
Isocyanates	1,270	130
Titanium dioxide	1,460	80
Fluoropolymers	255	25
Polycarbonates	1,050	110
Pharmaceuticals	46,120	5,680
Silicones	1,810	180
Miscellaneous	360	30
Total	71,430	8,460

SOURCE: Charles River Associates, 1993.

EMPLOYMENT AND WAGES

Having identified the products on the chlorine tree that depend on chlorine chemistry, CRA developed a primary database of plants that produce each of these products in the United States and Canada.

For each processing plant in the database, CRA collected information that identified the producing company and plant location, primary products, capacity, and estimated plant employment. This information was checked against other data sources like SRI's *Directory of Chemical Producers, Chemical Marketing Reporter, Lockwood-Post's Directory*, trade press, Census of Manufacturers, and Dun & Bradstreet reports. For PVC fabrication plants, CRA used industry data sources that identify PVC processing facilities by type of fabrication plant and by the estimated volume of PVC throughput. PVC throughput of these plants was consistent with CRA's estimates of PVC resin consumption. CRA estimated the employment of the PVC fabrication plants by type and size on a state by state basis, using information from the Society of the Plastics Industry. (1)

Public and private data sources provided information on plant employment for approximately 60 percent of the processing plants in the database. CRA estimated the remaining 40 percent by comparing plants of similar size and function if possible, and otherwise by using an appropriate industry average.

CRA aggregated its estimates of direct employment by state into three major categories: employment in chemical and allied product plants, employment in pulp mills, and employment in PVC fabrication plants. We estimated indirect employment by using regional employment multipliers published by the U.S. Department of Commerce Bureau of Economic Analysis. (2) Often called RIMS multipliers (Regional Input/Output Modeling System), these factors are used to calculate how many jobs in all industries will be created or lost by the creation or loss of one job in any other industry. CRA used the specific RIMS multipliers by state for the following Department of Commerce industry sectors: chemicals and petroleum refining, paper and allied products, and rubber and leather goods. Comparable multipliers for Canadian plants were based on the U.S. data.

In order to estimate direct wages, CRA used data from *County Business Patterns* (3), which reports average annual wage by industry sector by state.

CRA calculated indirect wages using other government sources. (4) All Canadian direct and indirect wage data was assembled from the *Canadian Statistics Yearbook.*

Total wages for the United States were calculated using the appropriate employment multipliers and average annual earnings for all manufacturing industries from the Bureau of Labor Statistics *Employment and Earnings.*

The industry directly employs nearly 400,000 workers and operates in 48 of the states in the United States and nine provinces in Canada. CRA identified over 800 processing plants that produce or depend on chlorine, and an additional 2,700 PVC fabrication facilities that would be closed or at least very severely affected by a chlorine ban. Since each manufacturing job creates secondary employment and wage effects, CRA estimates that in total almost 1.4 million workers depend on the chlorine industry. Total wages paid to these workers amounted to more than $33.6 billion in 1990. Ranked in terms of direct wages paid, the states and provinces are shown in Exhibit 4-13. Exhibits 4-14 and 4-15 depict the U.S. geographic distribution of these plants.

References

(1) The Society of the Plastics Industry, Inc., *Financial and Operating Ratios,* Survey No. 29, Plastic Processing Companies, July 1991.

(2) U.S. Department of Commerce, Bureau of Economic Analysis, *Regional Multipliers: A User Handbook for the Regional Input-Output Modelling System (RIMs II),* May, 1992.

(3) U.S. Department of Commerce, *County Business Patterns,* 1989.

(4) U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings,* August, 1991.

Exhibit 4-13. Estimated 1990 Employment and Wages Paid by Chlorine-Dependent Industries

	Number of Processing Plants	Number of PVC Fabrication Plants	Total Number of Plants	Direct Employment (Workers)	Total Attributable Employment (Workers)	Direct Wages ($Millions)	Total Wages ($Millions)
Texas	63	119	182	55,641	327,594	1,671	7,496
New Jersey	58	128	186	20,581	78,016	665	1,983
Ohio	30	219	249	26,076	78,592	631	2,239
Michigan	25	153	178	18,741	65,889	627	2,084
Louisiana	35	5	40	12,625	96,814	496	2,514
California	56	275	331	18,500	52,731	443	1,289
Pennsylvania	31	132	163	13,037	42,783	336	1,001
Indiana	12	143	155	13,106	36,181	326	1,006
New York	36	104	140	11,917	29,267	319	677
Illinois	31	130	161	10,867	39,116	314	970
Alabama	31	36	67	10,363	38,896	306	779
Tennessee	22	57	79	12,179	34,817	289	676
West Virginia	15	4	19	7,358	27,896	277	675
Kentucky	16	25	41	9,360	34,740	261	779
Florida	18	101	119	11,774	22,015	223	421
Georgia	22	48	70	9,486	23,773	220	465
North Carolina	22	70	92	9,519	25,848	214	475
Wisconsin	15	63	78	8,175	24,991	211	596
Oklahoma	4	10	14	8,596	27,112	206	619
Washington	21	19	40	5,722	17,099	182	461
Missouri	18	53	71	6,096	16,966	137	391
Virginia	10	28	38	4,868	12,548	129	288
Massachusetts	13	90	103	4,753	11,886	126	287
Mississippi	12	22	34	6,459	20,803	122	362
South Carolina	17	29	46	3,994	11,696	121	221
Minnesota	6	64	70	5,379	12,036	119	281
Delaware	8	32	40	2,683	9,706	116	285

(Exhibit continued on following page.)

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Exhibit 4-13 (continued)

	Number of Processing Plants	Number of PVC Fabrication Plants	Total Number of Plants	Direct Employment (Workers)	Total Attributable Employment (Workers)	Direct Wages ($Million)	Total Wages ($Million)
Connecticut	5	56	61	3,279	10,580	114	266
Kansas	4	31	35	5,525	16,501	112	382
Arkansas	9	24	33	4,320	10,372	92	189
Maryland	9	17	26	3,111	7,027	83	174
New Hampshire	4	25	29	2,647	6,441	70	150
Nevada	4	6	10	3,507	5,942	69	139
Oregon	6	26	32	3,257	7,204	68	162
Arizona	2	26	28	2,922	5,198	57	111
Nebraska	0	17	17	3,247	6,799	54	142
Iowa	7	13	20	2,314	6,370	53	150
Maine	8	10	18	617	1,621	21	39
Utah	4	15	19	963	2,544	17	54
North Dakota	0	5	5	1,501	2,527	17	47
Rhode Island	2	40	42	576	1,323	14	28
Colorado	1	43	44	598	1,263	11	30
Alaska	2	0	2	144	380	4	11
Idaho	1	3	4	116	327	3	7
New Mexico	2	3	5	111	497	2	10
Vermont	0	9	9	54	98	1	2
Hawaii	1	0	1	40	133	1	3
South Dakota	0	2	2	9	18	0	0
Montana	0	0	0	0	0	0	0
Wyoming	0	0	0	0	0	0	0
Total U.S.	718	2,530	3,248	366,738	1,314,971	9,939	31,349

(Exhibit continued on following page.)

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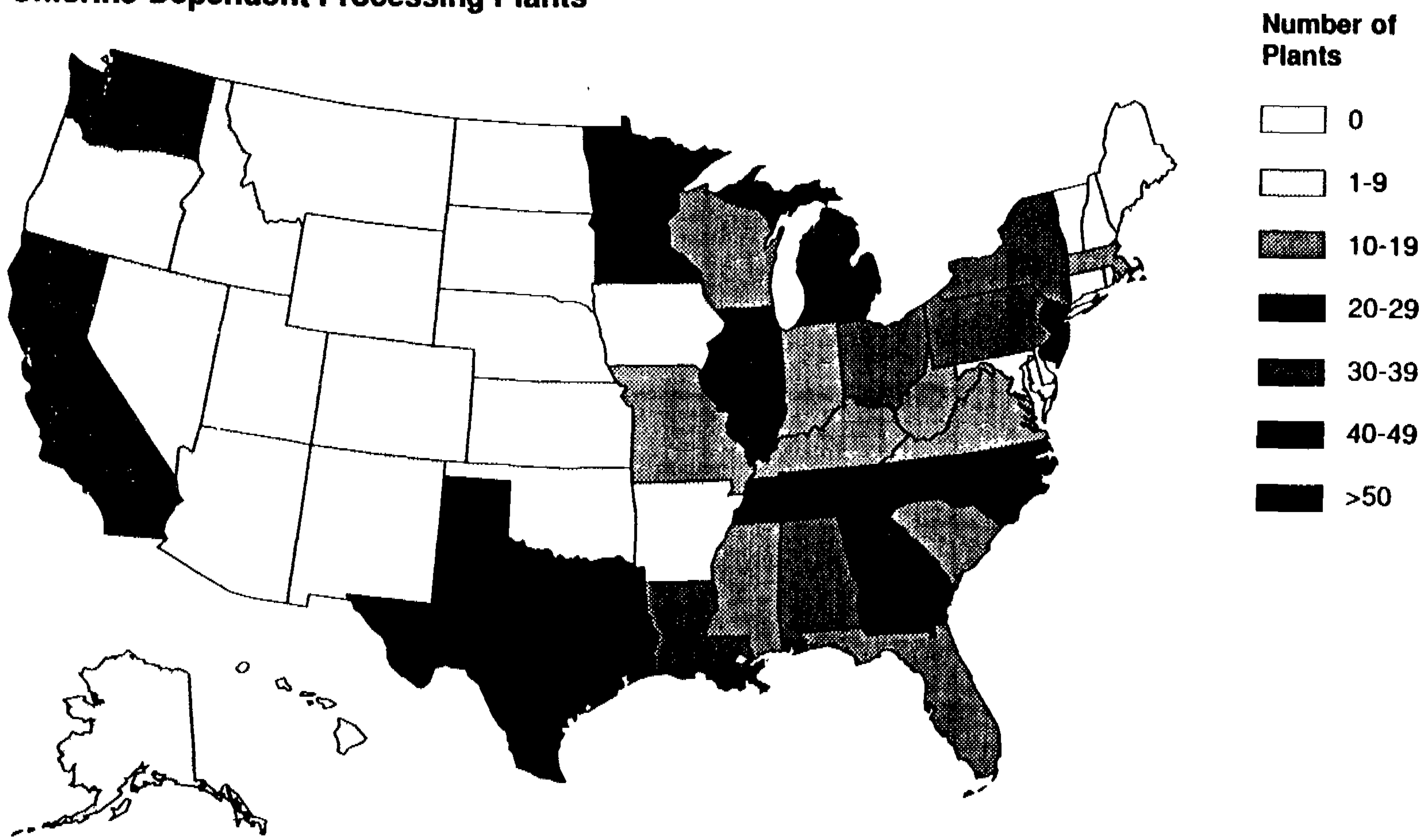
Exhibit 4-13 (continued)

	Number of Processing Plants	Number of PVC Fabrication Plants	Total Number of Plants	Direct Employment (Workers)	Total Attributable Employment (Workers)	Direct Wages ($Million)	Total Wages ($Million)
Ontario	29	61	90	9,902	32,614	268	861
British Columbia	27	56	83	6,322	16,915	171	457
Quebec	19	40	59	5,249	15,712	142	424
Alberta	13	27	40	3,692	11,208	100	303
New Brunswick	8	17	25	1,713	4,334	46	117
Nova Scotia	3	6	9	638	1,600	17	43
Saskatchewan	2	4	6	417	1,046	11	28
Prince Edward Island	1	2	3	211	561	6	15
Manitoba	1	2	3	206	539	6	15
All Other	0	0	0	0	0	0	0
Total Canada	103	215	318	28,350	84,529	766	2,283
Total U.S. and Canada	821	2,745	3,566	395,088	1,369,500	$10,706	$33,632

SOURCE: Charles River Associates, 1993.

Exhibit 4-14

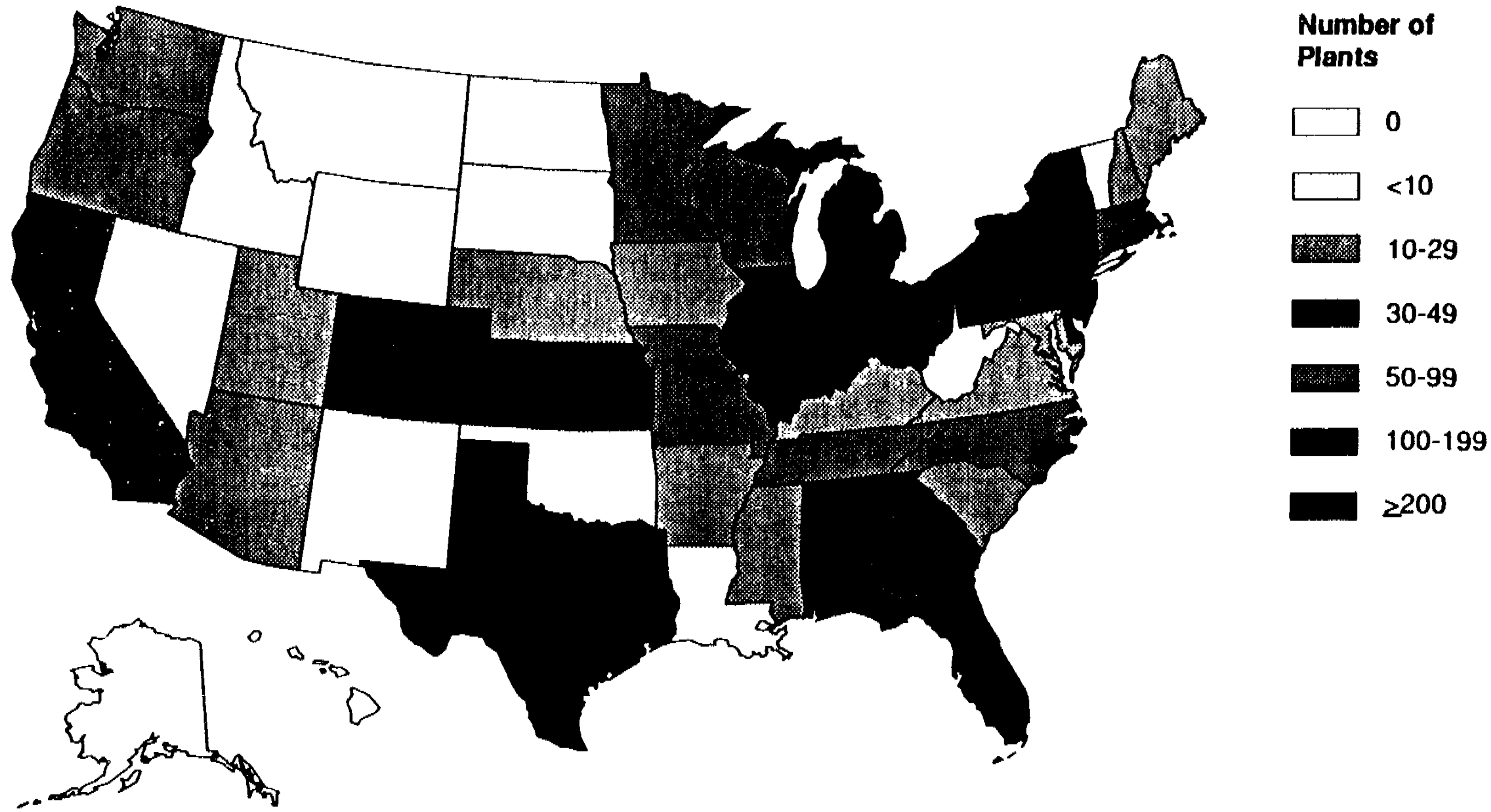
Chlorine-Dependent Processing Plants



Charles River Associates

Exhibit 4-15

PVC Fabrication Plants



INVESTMENT

CRA's estimated gross domestic fixed investment for chlorine-dependent plants was developed using data from the U.S. Census of Manufacturers, which reports on total employment and the value of depreciable assets by industry sector. CRA used the data for the following industries: inorganic chemicals, organic chemicals. alkalis and chlorine, plastics and resins, pulp and paper, and fabricated plastics. CRA calculated the value of assets per employee in each relevant sector, and then aggregated these estimates to determine total fixed-capital investment.

We estimated the gross domestic fixed investment of chlorine-dependent industries to be more than $61 billion. The geographical distribution of investment is similar to that of employment, except that primary processing plants tend to be large, capital-intensive operations and fabrication plants tend to be small, labor-intensive operations. As indicated above, these plants are located in nearly every state in the United States and most provinces of Canada. In the event of a chlorine ban, most of this amount of aggregate investment would be rendered obsolete, and the impacts would be felt across both nations. Exhibit 4-16 ranks the states and provinces that have the largest amount of in-place domestic investment in chlorine-dependent industries.

Exhibit 4-16. Estimated 1990 Investment in Chlorine-Dependent Industries

	Number of Processing Plants	Number of PVC Fabrication Plants	Investment in Processing Plants ($Million)	Investment in PVC Fabrication Plants ($Million)	Total Investment ($Million)
Texas	63	119	8,065	1,138	9,204
Michigan	25	153	4,655	87	4,742
New Jersey	58	128	4,464	187	4,651
Louisiana	35	5	3,202	46	3,248
Ohio	30	219	1,481	891	2,372
Alabama	31	36	2,273	112	2,385
New York	36	104	2,015	201	2,216
California	56	275	1,295	600	1,895
Illinois	31	130	1,644	211	1,855
West Virginia	15	4	1,768	40	1,808
Oklahoma	4	10	1,672	108	1,780
Pennsylvania	31	132	1,384	353	1,737
Tennessee	22	57	1,291	327	1,618
Wisconsin	15	63	1,443	140	1,583
Kentucky	16	25	1,197	219	1,416
Indiana	12	143	977	411	1,388
Washington	21	19	1,209	76	1,285
North Carolina	22	48	927	271	1,198
Georgia	21	48	922	272	1,194
Virginia	10	28	677	108	785
Florida	18	101	347	462	810
Mississippi	12	22	558	197	756
Connecticut	5	56	660	38	698
Missouri	18	53	457	191	647
Delaware	8	32	584	24	608
South Carolina	17	29	473	105	578
Massachusetts	13	90	395	143	538
Arkansas	9	24	347	137	484

(Exhibit continued on following page.)

CRA

Exhibit 4-16 (continued)

	Number of Processing Plants	Number of PVC Fabrication Plants	Investment in Processing Plants ($Million)	Investment in PVC Fabrication Plants ($Million)	Total Investment ($Million)
Kansas	4	31	234	201	435
Nevada	4	6	291	105	396
Maryland	9	17	315	86	402
New Hampshire	4	25	286	71	357
Minnesota	6	64	121	218	339
Iowa	7	13	200	68	268
Oregon	6	26	163	120	283
Maine	8	10	217	3	220
Arizona	2	26	39	121	160
Nebraska	0	17	0	140	140
Utah	4	15	55	33	88
North Dakota	0	5	0	65	65
Rhode Island	2	40	23	21	44
Alaska	2	0	62	0	62
New Mexico	2	3	28	0	28
Colorado	1	43	1	26	26
Idaho	1	3	31	2	33
Hawaii	1	0	11	0	11
Vermont	0	9	0	2	2
South Dakota	0	2	0	0	0
Montana	0	0	0	0	0
Wyoming	0		0	0	0
Total U.S.	718	2,530	48,459	8,377	56,837

(Exhibit continued on following page.)

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Exhibit 4-16 (continued)

	Number of Processing Plants	Number of PVC Fabrication Plants	Investment in Processing Plants ($Million)	Investment in PVC Fabrication Plants ($Million)	Total Investment ($Million)
Ontario	29	61	1,534	200	1,734
British Columbia	27	56	721	187	908
Quebec	19	40	687	131	818
Alberta	13	27	496	90	586
New Brunswick	8	17	164	55	219
Nova Scotia	3	6	62	21	83
Saskatchewan	2	4	35	14	49
Prince Edward Island	1	2	14	7	21
Manitoba	1	2	12	7	19
All Other	0	0	0	0	0
Total Canada	103	215	3,725	712	4,437
Total U.S. and Canada	821	2,745	52,184	9,090	61,274

SOURCE: Charles River Associates, 1993.

FOREIGN TRADE

Export and import data were collected from the U.S. Department of Commerce and from Statistics Canada at the detailed product or product class level. CRA assembled data for specific chlorine-dependent products including plastic resins and shapes. Fabricated plastics products were not included unless they could be separately identified.

Chlorine-dependent industries contribute more than $3.0 billion per year to the balance of merchandise trade. Among the major products that contribute to the positive trade balance are titanium dioxide, sodium hydroxide, silicones, PVC, polycarbonate resins, pharmaceuticals, and crop protection chemicals. As a whole, the U.S. chemicals and allied products industry is a significant competitor in world markets and enjoys a healthy net surplus in merchandise trade. This includes key sectors like organic and inorganic chemicals, plastics, crop protection chemicals, and pharmaceuticals. In 1990, the total chemical industry's surplus amounted to $16.5 billion. Thus, chlorine-dependent net trade of $2.9 billion represents about 18 percent of the industry's total. In the event of a chlorine ban, this trade surplus would disappear and, unless the rest of the world followed suit, the United States and Canada would be at a severe competitive disadvantage in world trade in these chemicals. Exhibits 4-17 and 4-18 summarize the value of chlorine-dependent products imports and exports for the United States and Canada, respectively.

Exhibit 4-17. Estimated 1990 U.S. Exports and Imports of Chlorine-Dependent Products

Product	Value of Exports ($Million)	Value of Imports ($Million)	Value of Net Trade ($Million)
Pharmaceuticals	1,111	579	+532
Crop protection chemicals	1,013	200	+813
Titanium dioxide	423	308	+114
Sodium hydroxide	411	149	+262
PVC resin	365	66	+299
Silicone resins	311	79	+232
Polycarbonate resins	260	34	+226
Polysulfones	174	77	+97
TDI	154	4	+149
Vinyl chloride monomer	150	40	+110
Polychloroprene	125	21	+104
Propylene oxide	114	20	+94
PVC shapes	100	303	-203
Ethylene dichloride	96	8	+88
Epoxy resins	89	48	+41
Propylene glycol	81	4	+77
1,1,1-Trichloroethane	27	2	+26
Calcium hypochlorite	26	7	+20
Epichlorohydrin	26	14	+10
All Others	283	501	-218
Total	5,339	2,464	+2,873

Note: Numbers may not add because of independent rounding.

SOURCE: U.S. Department of Commerce.

Exhibit 4-18. Estimated 1990 Canadian Exports and Imports of Chlorine-Dependent Products

Product	Value of Exports ($Million)	Value of Imports ($Million)	Value of Net Trade ($Million)
PVC resin	99	162	-63
Chlorine	34	40	-6
Aluminum chloride	-	12	-12
Hydrochloric acid	5	5	0
Sodium chlorate	115	5	+110
Propylene glycol	-	4	-4
1,1,1-Trichloroethane	-	4	-4
Methylene chloride	-	4	-4
Calcium hypochlorite	6	3	+3
Titanium dioxide	9	2	+7
Vinyl chloride monomer	40	-	+40
Ethylene dichloride	32	-	+32
All others	22	13	+9
Total	362	254	+108

Note:

(1) Pharmaceuticals and crop protection chemicals are not included here because most of the trade in these chemicals occurs between the United States and Canada.

(2) Numbers may not add because of independent rounding.

SOURCE: Charles River Associates, 1993, based on data from TRADSTAT.

Economic Contributions

SUMMARY

As described above, CRA's analysis establishes that chlorine-dependent industries contribute to the economy of the United States and Canada in a variety of ways. Using a conservative definition, chlorine-dependent industries provide direct employment opportunities for over 400,000 workers. Considering the indirect employment opportunities, chlorine-dependent industries account for nearly 1.4 million jobs. These jobs can be found in 48 states and nine Canadian provinces. The direct wages paid to workers in chlorine-dependent industries amounted to nearly $11 billion, while total wages amounted to over $33 billion. These wages are spent in various local economies and are paid to the government in the form of income and other taxes.

The manufacturing activities for chlorine-dependent products generate sales of almost $80 billion per year, based on 1990 consumption patterns and prices. This represents a significant volume of economic transactions that become part of a region's stock of wealth and annual flow of income. The existing plant and equipment in place amounts to an estimated $61 billion in 1990. This capital stock would be rendered obsolete by a ban on chlorine production.

Finally, the industry contributes to the net balance of foreign trade for the United States by exporting over $2.9 billion more products than it imports. Net exports for the Canadian industry are negligible. In the event of a chlorine ban, U.S. and Canadian industries would be at a severe competitive disadvantage in world trade; our favorable cost position would deteriorate and all downstream affected industries would face higher costs of substitute products not based on chlorine chemistry.

In summary, the products of chlorine-dependent industries are pervasive in the economies of the United States and Canada. They generate a substantial volume of sales, provide a sizable number of jobs, and contribute to the local economies in countless visible and not-so-visible ways. Chlorine chemistry has been tremendously influential in the daily lives of consumers, and any proposal to prohibit chlorine use will have far-reaching consequences for society's economic welfare. However, this in no way relieves policy makers and others from

monitoring and regulating specific products to restrict or eliminate those that are deemed to present unacceptable risks to human health or the environment.

5
Macroeconomic Measurement of the Chlor-Alkali Industry's Contributions

In addition to the detailed analysis above, CRA has used a macroeconomic approach to measure the economic contributions of the chlor-alkali industry. This method complements our microeconomic analysis by its more expansive nature, and captures the less obvious of these contributions.

CRA's macroeconomic measurement is based on the U.S. Department of Commerce 1987 Interindustry Transactions Table. This table contains data that show, for the United States in 1987, the flow of material from the industries producing commodities to the industries and final consumers using them. In its most detailed form, the table consists of 475 distinct producing industries and the commodities they produce and consume. One of the sections in the table shows, for example, the amount of steel used directly by the motor vehicle parts and accessories industry in 1987. Similarly, another section shows the amount of chlor-alkalis used directly by the soaps and detergents industry. The table shows the measurable amounts of all the various industries' outputs used in the production processes of each of the 475 producing industries in 1987.

The Interindustry Transactions Table also includes several "special" industries and more than 25 categories of final product demands made by private households, governments, and exports. As a result, it is a fully comprehensive and inclusive depiction of the U.S. economy.

Inspecting the entries shows the economy's complexity. All individual industries depend on several other industries for the materials they use in their production processes. Consequently, the interindustry commodity flows, which constitute the intermediate demands for these products, weave an extensive and intricate web of mutual interdependence among the producing sectors. Any particular industry may not only use its own and other industries' output directly in its production processes, but it may also find that it "indirectly" depends on its own product because some of its commodity suppliers use this product in a direct or circuitous way. For example, the petroleum refining industry consumes some of its own products directly in the form of fuel burned for energy to run its refineries. It also consumes its own products indirectly as it uses other raw materials and supplies that involve refinery-produced fuels or feedstocks in their production.

Interindustry transactions tables are generally accepted and widely used as tools in macroeconomic evaluations of the economic effects of regulatory initiatives and other external forces. They are the basis of countless public and private sector analyses that require measures of the interconnections between the economy's various sectors. Many European and Asian countries develop interindustry transactions tables of their own economies, some in even more detail than the U.S. tables. The obvious strength of such an approach is that it helps account for the extensive interdependencies that exist in the economy. But it must also be used with some caution.

To use these tables properly, one must first understand the scope and use patterns of an industry's outputs so that the totals can be disaggregated and the flows of individual commodities tracked to the appropriate consuming industries. For example, chlor-alkali products listed include soda ash, and we have had to delete the sales of this material from the total to isolate the sales of chlorine and coproduced sodium and potassium hydroxides. Also, the transactions represent a description of the economy at a particular time. As industries change their production processes, a static description eventually loses some of its accuracy. The fuel consumption patterns in 1968, for example, are hardly the same as those that evolved after 1973. Also, this description of the economy at a particular time probably does not reflect the extent of the flexibility that can be exercised in the pattern of input use by various industries and in the patterns of their outputs. Nevertheless, the Interindustry Transactions Table is indispensable for gaining insights into what actually took place in 1987 and the forms of direct and indirect (and therefore less evident) interdependencies that existed then. These tables are generally updated every five years. The 1992 version is scheduled to be published during 1994.

The 1987 U.S. interindustry flows or transactions data can be used in two quite different types of analyses of the economic contribution of chlor-alkalis. The first of these may be imagined as an "upstream" perspective on this contribution. This perspective inquires into the incomes and employment that are generated in the production of chlor-alkalis themselves. That is, what commodities and other inputs do chlor-alkali producers use both directly and indirectly in their production processes and how much employment and income are generated as a result? Since this perspective is comparable to the analysis using the RIMS multipliers described in previous chapters of this study, we will not discuss it further here.

The second type of analysis takes a "downstream" view of the economic contribution of chlor-alkalis. From this perspective, the interindustry transactions data provides insights into the extent to which chlor-alkalis "cascade" out through the economy. As described earlier, they may be used directly, they may be used as components of commodities produced subsequently in the production stream, or they may be used to facilitate the production processes employed in other industries. Interindustry transactions data do not distinguish among these types of uses. Moreover, in interindustry transactions data, the production stream flows are not unidirectional; some of the "downstream" products may be "channeled" back upstream to support "earlier" industry production. The contribution of chlor-alkalis from this perspective consists of the employment and incomes that are generated in the industries that use chlor-alkalis and their derivatives directly or indirectly, regardless of the type of use.

DOWNSTREAM CONTRIBUTIONS

From the downstream perspective of the chlor-alkali industry, we view the industry (or any other industry for that matter) as a production point that distributes its product to other industries. These industries then use it in their production processes and in turn distribute their own products to still other industries.

The downstream approach utilizes the interindustry transactions data in the first instance to trace the flow of chlor-alkalis directly into specific using industries. Regardless of the nature of the application of chlor-alkalis in those industries' production processes, their products thus "embody" chlor-alkalis. In the next "round" of transactions, the approach traces the flow of the products that embody chlor-alkalis from the industries producing them to still other industries. Such subsequent rounds could be repeated as many times as necessary to trace the flow of chlor-alkali-dependent products to the final consumer. The economic contribution of the chlor-alkali industry from this perspective consists of the incomes and employment generated in this manner. In other words, if an industry uses chlorine and its coproducts directly or indirectly, the employment and incomes generated in that industry are considered to be part of the chlor-alkalis' contribution. This is distinguishable from the benefits analysis reported in Chapter 3, where an assessment was made of the ease or difficulty with which industries or consumers might discontinue the use of chlor-alkalis through substitution. In contrast, downstream analysis directly examines which industries used chlor-alkalis or products embodying chlor-alkalis in 1987. It goes on to measure contribution according to the incomes and employment generated by those industries.

THE INTERINDUSTRY DISTRIBUTION OF CHLOR-ALKALIS

The smallest unit of measurement of the distribution of products to industries in the 1987 Interindustry Transactions Table is $100,000. CRA has carried all of the transactions at this level along in its computations, rather than applying a higher cut-off. The rationale for this is derived from a major finding of the benefits analysis: the value of chlorine to the consumer does not depend on the *amount* used, but on the *use* to which it is put. The interindustry transactions data are on a "current" basis and, in the case of chlor-alkalis, this means that the very large amounts of chlorine that are used in the titanium pigments and titanium sponge industries, for example, are not shown because these industries maintain substantial inventories of chlorine that are recovered and recycled continuously. The same applies to numerous other industries that use and recycle chlorinated compounds or intermediates. Only current "make-up" quantities or amounts obtained to sustain their capacities to produce are recorded. Since we cannot determine chlorine's utility in all of these industries without an exhaustive analysis, and since we do not wish to ignore small but important uses (such as the production of catalysts), we have included all measured transactions.

However, CRA did apply its technical and business judgment to adjust the chlor-alkali data in the transactions table. Including soda ash with chlorine and its coproduct hydroxides would not be appropriate for this analysis. Consequently, we have investigated, item by item, the distribution of chlor-alkalis shown in the transactions table and removed soda ash use from the data of those industries that consume it.

Exhibit 5-1 lists the industries that the Interindustry Transactions Table shows to have used chlor-alkalis in 1987. Use amounts were adjusted by CRA to exclude soda ash. The list includes 212 chlor-alkali-using industries that make up the first round of the distribution of chlor-alkalis and products embodying chlor-alkalis through the economy. These 212 industries constitute almost 45 percent of all the producing industries delineated in the Interindustry Transactions Table.

The "first round" industries accounted for over 45 million of the more than 115 million jobs in the U.S. economy in 1987. They also generated more than $1.6 trillion of the more than $4.5 trillion of U.S. national income. That is about 39 percent of the total jobs and almost 36 percent of the total national income in 1987. CRA then extended the analysis to trace the distribution of products made by the 212 industries that used chlor-alkalis directly. We found that in the course of this "second round," all 475 of the producing industries included in the Interindustry Transactions Table became either direct users of chlor-alkalis or users of products embodying chlor-alkalis.

Our analysis suggests that the entire economy is touched by chlor-alkalis or products derived from them within only two rounds of transactions. It could be argued that similar conclusions might be drawn for many other commodities (e.g., steel), particularly if the cut-off level for the transactions were set low enough. To test the sensitivity of the results to the level of transactions followed, we analyzed the downstream consumption of chlor-alkalis in industries that consumed more than $1 million of these materials in 1987. At the higher cut-off level we still found that 92 consuming industries using the chlor-alkali products directly, and that they accounted for more than $700 billion of national income and over 13 million jobs, or about 20 percent of all industries, 15 percent of the national income, and 11 percent of the total jobs in the economy. At this cut-off level three or more rounds of transactions would be required to touch all sectors, but the conclusions remain the same: chlor-alkalis pervade the economy and support a very large fraction of its activity.

CONCLUSIONS

On the basis of this analysis it is clear that chlor-alkalis are widely diffused throughout the U.S. economy. Using data adjusted by CRA to avoid including the use of soda ash, the analysis showed that about 45 percent of U.S. industries used chlor-alkalis in 1987 and that these industries generated more than 36 percent of the income and jobs in the economy that year.

We recognize that the "technology" imbedded in the 1987 U.S. Interindustry Transactions Table differs from the technology in use in 1990 and today. Chlorine and caustic consumption has decreased in pulp and paper manufacturing, for example, and chlorine consumption in the manufacture of refrigerants and solvents has decreased as the consumption of the final products has decreased. However, the 1992 version of the transactions table will undoubtedly resemble the 1987 version by showing that the chlor-alkali industry's products are used throughout the economy, and that the chlor-alkali industry itself will be a major consumer for a large segment of the economy.

To summarize, the macroeconomic analysis confirms and extends the analyses presented in the previous chapters: because use of chlorine and coproducts is so pervasive, a ban on chlorine production would be felt in *all* sectors of the economy. About 45 percent of all U.S. industries use these products directly, while every industry is an indirect consumer of these products.

Exhibit 5-1. Industries Using Chlor-Alkalis Directly[1]

Forestry products	Soybean oil mills
Commercial fishing	Roasted coffee
Iron and ferroalloy ores mining	Shortening and cooking oils
Copper ore mining	Food preparations, n.e.c.
Nonferrous metal ores mining, except copper	Cigarettes
Coal mining	Chewing and smoking tobacco
Crude petroleum and natural gas	Broadwoven fabric mills and fabric finishing plants
Dimension, crushed and broken stone mining and quarrying	Yarn mills and finishing of textiles, n.e.c.
Sand and gravel mining	Thread mills
Clay, ceramic, and refractory minerals mining	Floor coverings
Nonmetallic mineral services and miscellaneous minerals mining	Felt goods, n.e.c.
Chemical and fertilizer mineral mining	Padding and upholstery filling
Meat packing plants	Processed textile waste
Sausages and other prepared meats	Coated fabrics, not rubberized
Poultry dressing plants	Tire cord and fabric
Cheese, natural and processed	Nonwoven fabrics
Ice cream and frozen desserts	Textile goods, n.e.c.
Fluid milk	Women's hosiery, except socks
Canned specialties	Knit fabric mills
Canned fruits and vegetables	Apparel made from purchased materials and dressed furs
Dehydrated food products	Logging camps and logging contractors
Pickles, sauces, and salad dressings	Sawmills and planing mills, general
Frozen fruits, fruit juices and vegetables	Wood preserving
Frozen specialties	Mattresses and bedsprings
Flour and other grain mill products	Metal office furniture
Blended and prepared flour	Wood partitions and fixtures
Dog, cat, and other pet food	Metal partitions and fixtures
Prepared feeds, n.e.c.	Drapery hardware and blinds and shades
Bread, cake, and related products	Pulp mills
Cookies and crackers	Paper mills, except building paper
Sugar	Paperboard mills
Confectionery products	Building paper and board mills
Chocolate and cocoa products	Paper coating and glazing
Chewing gum	Bags, except textile
Malt beverages	Pressed and molded pulp goods
Bottled and canned soft drinks	Converted paper products, n.e.c.
Flavoring extracts and syrups, n.e.c.	Paperboard containers and boxes
	Periodicals

(Exhibit continued on following page.)

Exhibit 5-1 (continued)

Commercial printing
Lithographic platemaking and services
Alkalis and chlorine
Inorganic pigments
Industrial inorganic chemicals, n.e.c. excluding alumina
Industrial organic chemicals except gum and wood chemicals
Nitrogenous and phosphatic fertilizers
Agricultural chemicals, n.e.c.
Gum and wood chemicals
Adhesives and sealants
Explosives
Printing ink
Chemical preparations, n.e.c.
Plastics materials and resins
Synthetic rubber
Cellulosic synthetic fibers
Organic fibers, noncellulosic
Drugs
Soap and other detergents
Polishes and sanitation goods
Surface active agents
Toilet preparations
Paints and allied products
Petroleum refining
Lubricating oils and greases
Paving mixtures and blocks
Asphalt felts and coatings
Tires and inner tubes
Rubber and plastics footwear
Fabricated rubber products, n.e.c.
Miscellaneous plastics products
Rubber and plastics hose and belting
Leather tanning and finishing
Boot and shoe cut stock and findings
Shoes, except rubber
Leather goods, n.e.c.
Glass and glass products, except containers
Glass containers
Cement, hydraulic
Brick and structural clay tile
Ceramic wall and floor tile
Vitreous plumbing fixtures
Ready-mixed concrete
Lime
Gypsum products
Abrasive products
Asbestos products
Gaskets, packing and sealing devices
Minerals, ground or treated
Mineral wool
Nonclay refractories
Nonmetallic mineral products, n.e.c.
Blast furnaces and steel mills
Steel wire and related products
Iron and steel foundries
Iron and steel forgings
Metal heat treating
Primary metal products, n.e.c.
Primary copper
Primary lead
Primary zinc
Primary aluminum and alumina
Copper rolling and drawing
Aluminum rolling and drawing
Nonferrous rolling and drawing, n.e.c.
Nonferrous wire drawing and insulating
Nonferrous castings, n.e.c.
Nonferrous forgings
Metal cans
Fabricated structural metal
Metal doors, sash, and trim
Fabricated plate work (boiler shops)
Sheet metal work
Automotive stampings
Metal stampings, n.e.c.
Plating and polishing
Metal coating and allied services
Pipe, valves, and pipe fittings

(Exhibit continued on following page.)

Exhibit 5-1 (continued)

Fabricated metal products, n.e.c.	Dental equipment and supplies
Construction machinery and equipment	Photographic equipment and supplies
Oil field machinery	Jewelers' materials and lapidary work
Machine tools, metal cutting types	Hard surface floor coverings
Machine tools, metal forming types	Manufacturing industries, n.e.c. excluding fur dressing
Special dies and tools and machine tool accessories	Railroads and related services
Special industry machinery, n.e.c.	Motor freight transportation and warehousing
Industrial patterns	Private electric services (utilities)
Machinery, except electrical, n.e.c.	Private water supply and sewerage systems
Refrigeration and heating equipment	Sanitary services, steam supply, and irrigation systems
Service industry machines, n.e.c.	Wholesale trade
Transformers	Laundry, cleaning, garment services and shoe repair
Carbon and graphite products	Funeral service and crematories
Electrical industrial apparatus, n.e.c.	Electrical repair shops
Household refrigerators and freezers	Watch, clock, jewelry, and furniture repair
Electric lamps	Services to dwellings and other buildings
Lighting fixtures and equipment	Management consulting services and testing and research labs
Wiring devices	Other business services
Radio and TV communication equipment	Eating and drinking places
Electron tubes, all types	Private hospitals
Semiconductors and related devices	Private nursing and personal care facilities
Other electronic components	Other medical and health services, excluding nursing homes
Storage batteries	Private elementary and secondary schools
Primary batteries, dry and wet	Private colleges, universities, and professional schools
Electrical equipment and supplies, n.e.c.	Private libraries, vocational schools, & educational services, n.e.c.
Motor vehicles and car bodies	Other state and local government enterprises
Motor vehicle parts and accessories	
Aircraft and missile equipment, n.e.c.	
Ship building and repairing	
Railroad equipment	
Environmental controls	
Surgical and medical instruments	
Surgical appliances and supplies	

(1) Chlorine and sodium and potassium hydroxides only. Excludes soda ash.

SOURCE: Charles River Associates, based on 1987 Interindustry Transactions Table.

APPENDIX A
Cobb–Douglas Production Functions

Production functions are economic models of the production process. In order to avoid complex analytical intricacies, one can postulate that a simple relationship exists between the output of an industry, Q, and the various factors of production. In such a model, the production function can take on the following general form:

$$Q = f(K, L, M, ...),$$

where Q represents the output of a particular industry during a time period, K represents the amount of capital employed in the industry during the time period, L represents the hours of labor input during the period, and M represents the quantity of raw materials consumed during the time period. There may be other variables entering the analysis as well. The form of this model suggests that decision makers can choose different combinations of the various factors of production to achieve various levels of output. These trade-offs between factor inputs and different levels of output define the shape and key characteristics of the production process.

For practical purposes, economists have conducted thousands of empirical studies of actual production relationships in a wide variety of industries using various types of production functions. At the aggregate level, they can provide useful ways to understand the inter-relationships between the level of output and different combinations of factor inputs.

A special case of this class of economic model is called the Cobb–Douglas production function. Cobb–Douglas functions can be defined mathematically as follows:

$$Q = f(K, L, M, ...) = AK^{a} L^{b} M,^{c}$$

where A, a, b, and c are all positive constants. When $a + b + c = 1$, the Cobb–Douglas function exhibits two useful and interesting properties: constant returns to scale and constant elasticity of substitution. Constant returns to scale means that doubling all factors of production will result in a doubling of output.

Cobb–Douglas Production Functions

The elasticity of substitution is a measure of how easy or difficult it is to substitute one input for another. Mathematically, it can be defined for Cobb–Douglas functions with two factor inputs as:

$$\sigma = \frac{(\partial Q/\partial L) \ x \ (\partial Q/\partial K)}{Q \ x \ (\partial^2 Q/\partial L \partial K)} = 1.$$

In a simple example, suppose there are only two factors of production, labor (L) and capital equipment (K). The trade-off between these two factors of production in a Cobb–Douglas function can be depicted in Exhibit A-1 as a set of isoquant maps, where an isoquant map is defined as the alternative combinations of productive inputs that can be used to produce a given level of output. The different levels of output are represented by the contour lines Q_1, Q_2 and Q_3.

In CRA's production function model for agriculture and pharmaceutical products, we assume that the coefficients a, b, and c can be defined as the expenditure share of each factor input K, L, and M. This is equivalent to assuming constant elasticity of substitution among the factors of production, and we calculate:

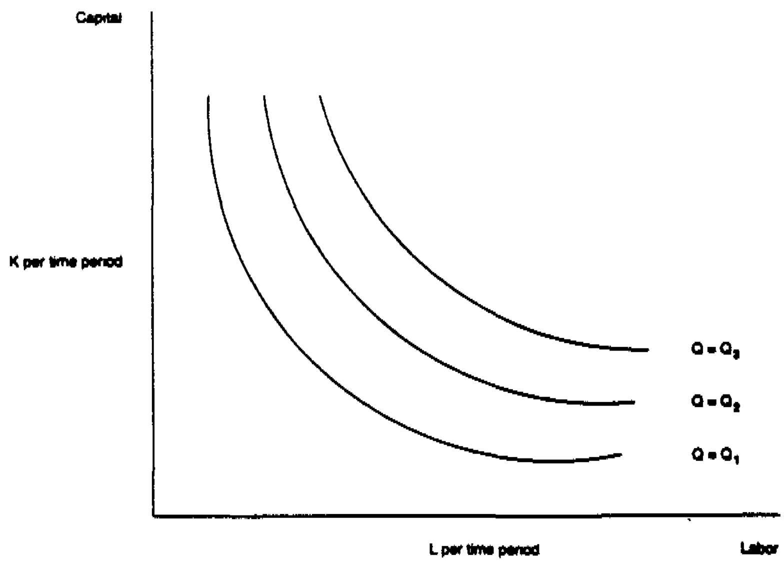
$$a = \frac{K}{K+L+M},$$

$$b = \frac{L}{K+L+M},$$

$$c = \frac{M}{K+L+M}.$$

In the event of a chlorine ban, we solve this mathematical model to estimate how much the other factors of production would have to increase in order to compensate for the loss of chlorine-based products.

Exhibit A-1
COBB-DOUGLAS PRODUCTION FUNCTION ISOQUANTS



SOURCE: Charles River Associates, 1993.

Charles River Associates

Charles River Associates, with offices in Boston and Washington, D.C., is an economics, engineering, and management consulting firm. Our professional staff includes: economists; chemical, biochemical, polymer, and materials engineers; geologists and chemists; MBAs; operations research specialists; and financial analysts. Many have decades of industry experience. CRA consults to business executives on a range of strategic and marketing issues. Our projects generally span a broad spectrum — with purely economic analysis at one end, purely technological analysis at the other, and a wide range of projects in between that require multidisciplinary teams of skilled experts. We also have extensive consulting experience with U.S. and foreign government agencies at the federal, state, and local levels. The firm's major areas of expertise include:

- Business strategy, economics, and market and technology assessment in chemicals, pharmaceuticals, polymers, minerals, and metals;
- Environmental and occupational safety regulation in these industries;
- Energy economics and management;
- Transportation planning and economics; and
- Economic analysis and support for litigation.

The strength we offer our clients in these areas is the breadth and depth of our team's experience. Since our founding in 1965, CRA has assisted international companies to evaluate opportunities such as:

- Strategic and business planning,
- World market studies, market research, and development,
- Economic and policy analysis and pricing strategy development,
- Prefeasibility studies, process engineering, and cost estimations, and
- Development and commercialization strategies for new technologies.

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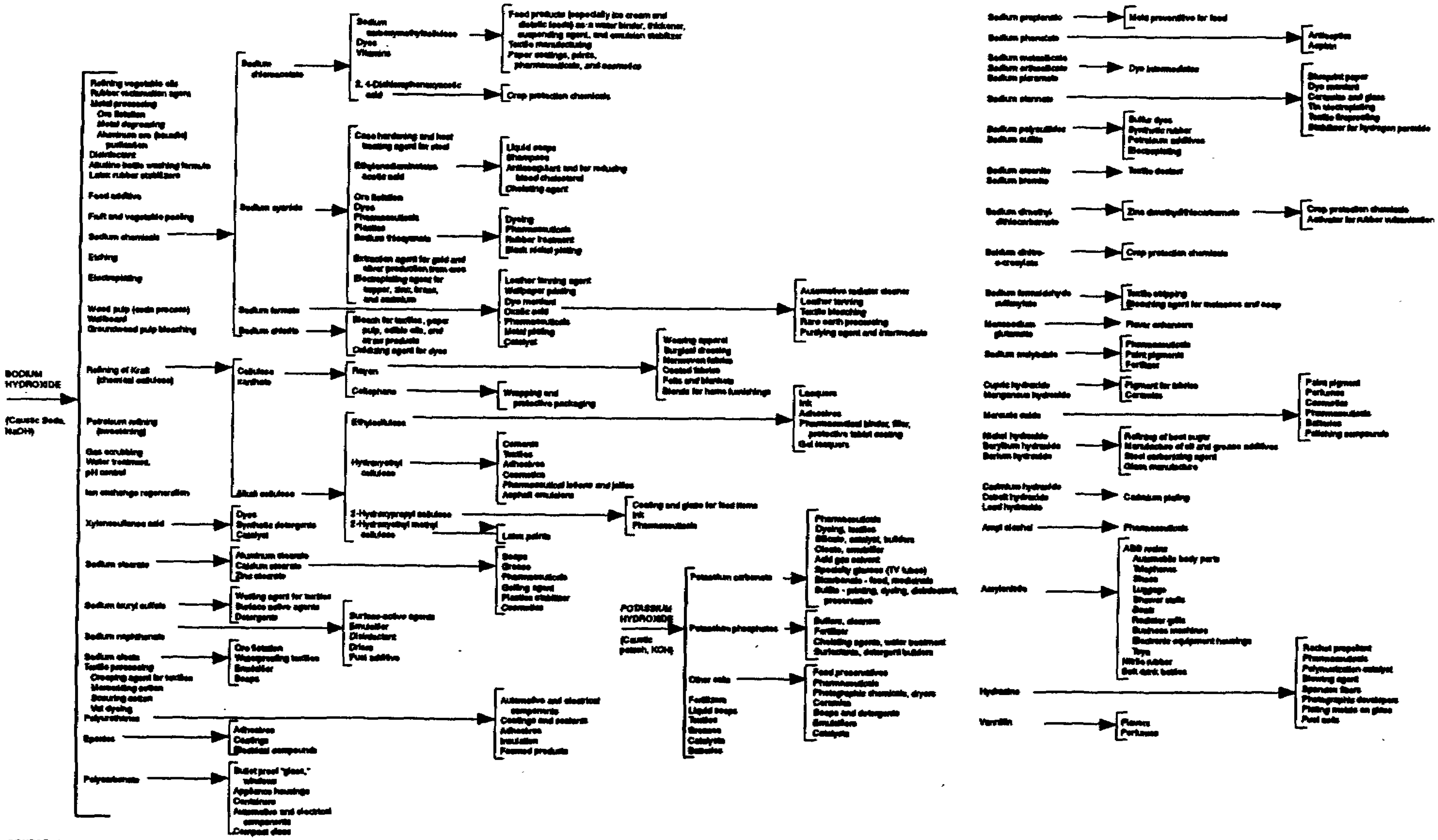
CRA

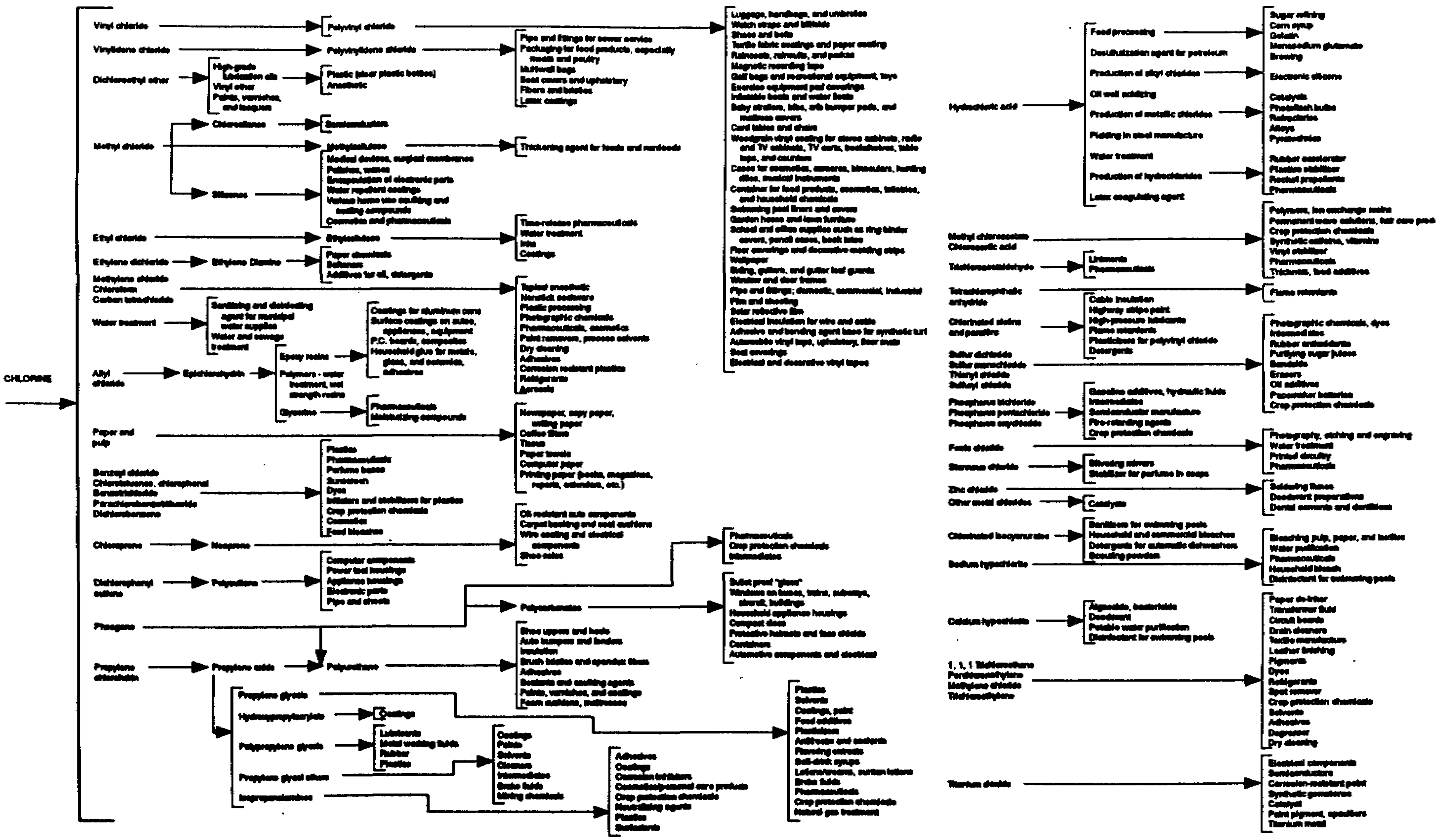
SODIUM AND POTASSIUM HYDROXIDE CHEMISTRY AND PRODUCT TREES



SOURCE: Charles River Associates, 1993.

CMA 110762

CHLORINE CHEMISTRY AND PRODUCT TREE

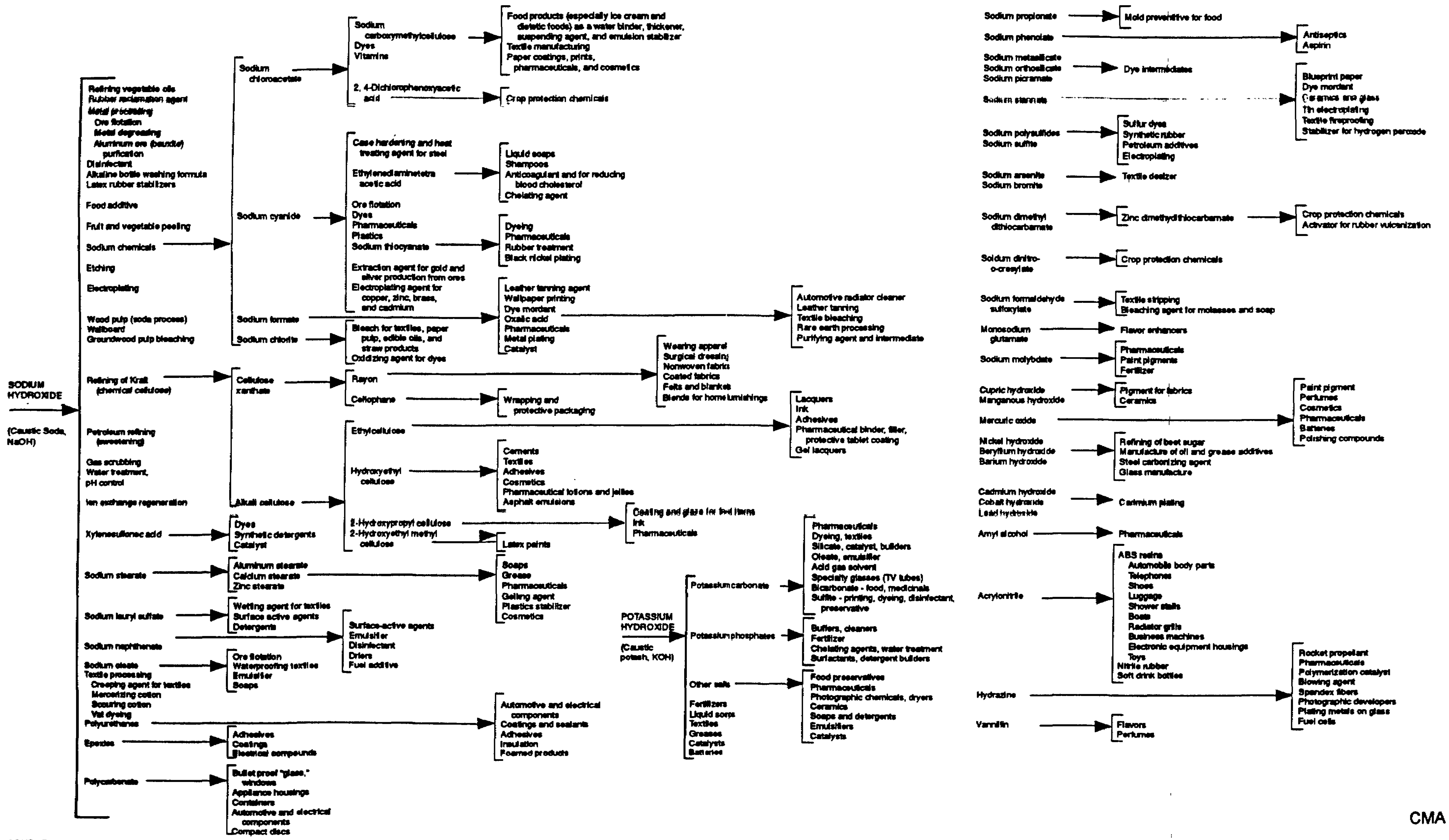


CMA 110763

SOURCE: [illegible]

APPENDIX B
Product Trees for Chlorine, Sodium Hydroxide, and Potassium Hydroxide

SODIUM AND POTASSIUM HYDROXIDE CHEMISTRY AND PRODUCT TREES



SOURCE: Charles River Associates, 1993.

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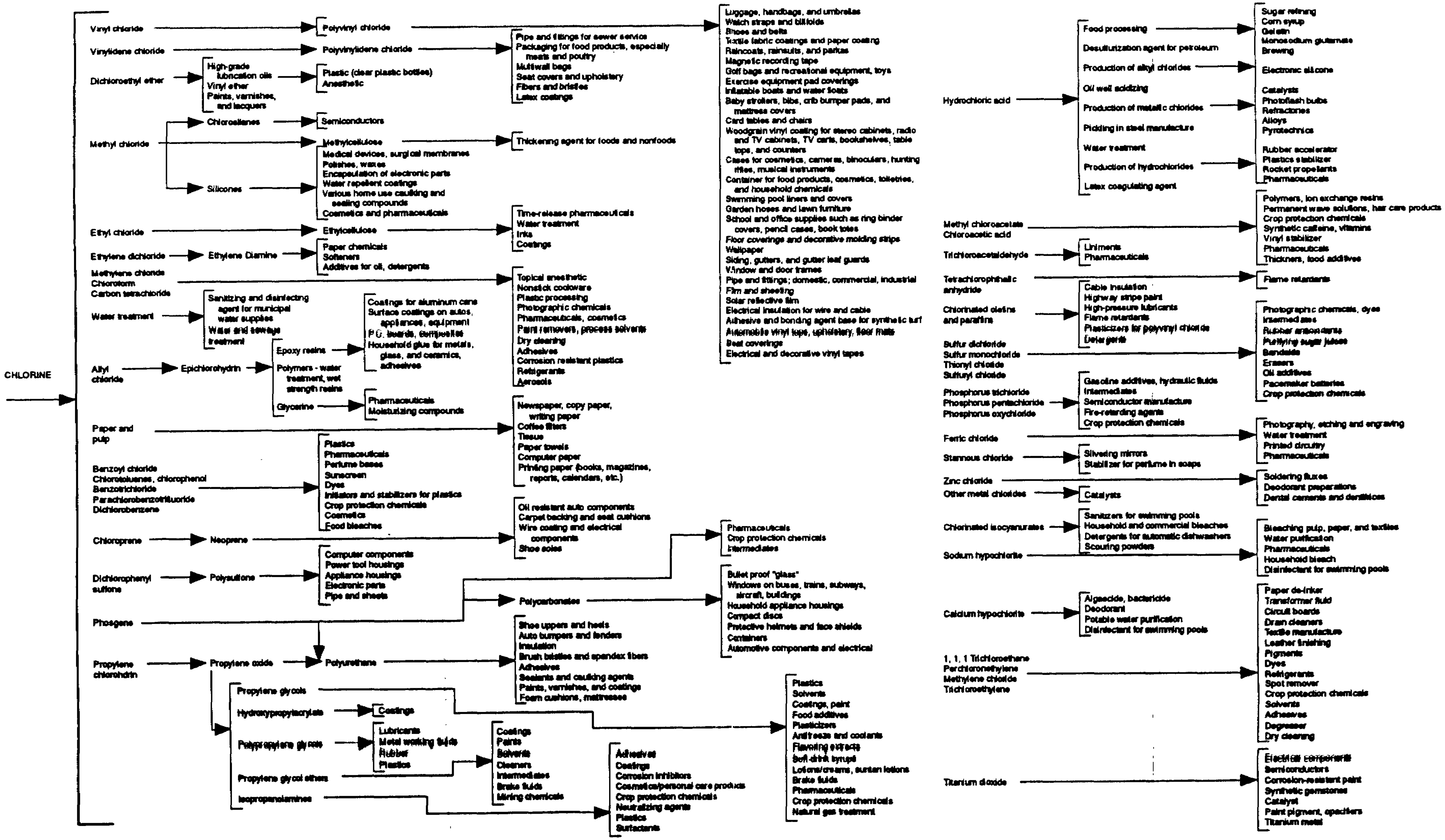
CHLORINE CHEMISTRY AND PRODUCT TREE



SOURCE: Charles River Associates, 1993.

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